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CONTENTS

Articles

Page
Editorial—From Basic Concept to Clinical Use—A. B. Wilson . 1
Myoplastic Techniques—G. Murdoch 4
Knee-Disarticulation Amputation—G. Murdoch 14
The Below-Knee Amputation—E. M. Burgess 19
Conservation of Energy in Ambulation—V. T. Inman 26
Prosthetics Advances Speeding Recovery of Amputees 36
Clinical Evaluation of the Cetrone Belt—E. A. Lewis and W. M. Bernstock 40
Survey of Upper- and Lower-Extremity Brace Components—W. J. McIlmurray 50
A Review of the Veterans Administration Blind Guidance Device Project—J. M. Benjamin, Jr. 63
Short Term Field Evaluation of Type 8A9 Ultrasonic Aid for the Blind—R. R. McClung 91
The Visotoner: A Personal Reading Machine for the Blind—H. L. Lauer 99
An Evaluation of the CROS-Type Hearing Aid—S. H. Lotterman, R. N. Kasten, and S. G. Revoile 104
Physical Performance of Hearing Aids as Affected by Receiver Substitution—G. R. Simon 110
Hearing-Aid Evaluation: An Examination of Two Procedures—G. Nance and G. D. Causey 119

VA Prosthetics Center Research

Introduction—A. Staros 125
Report—E. Peizer et al. 128

Highlights of Other VA Research Programs

Prosthetics—E. F. Murphy and W. M. Bernstock 181
Sensory Aids—H. Freiberger 193

Departments

Notes and News 202
Recent Patents 207
Publications of Interest 208
Calendar of Events 211

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FROM BASIC CONCEPT TO CLINICAL USE

. . . guest editorial

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Biomedical engineering, or the application of the principles of engineering and the physical sciences to the solutions of health problems, is now recognized as an important entity. Some aspects merge with overlapping fields with similar names such as bioengineering, medical engineering, biomechanics, and human factors. Committees of the National Academy of Engineering and other groups, divisions of existing societies, and special societies here and abroad have been formed to promote exchange of information and to carry out specific programs. Special journals are available, many conferences concerning one or more aspects of this broad subject are held each year, and biomedical engineering in various forms is receiving increasing attention not only in universities, as Dean Ragazzini and Mr. Contini discussed in the past issue, but in government and industry.

There is a great deal of concern about the effectiveness of effort in this rather new interdisciplinary field, with expressions of impatience with delays in acceptance of new developments, as exemplified in a recently published report of the United States Senate.[a]

Possibly encouragement may be found in a specific example, the "Artificial Limb Program," a pioneering effort in the field of biomedical engineering, initiated in 1945 by the National Research Council at the request of the Surgeon General of the Army. The Artificial Limb Program has unquestionably revolutionized its field, and, though constant self-examination emphasizes that much remains to be done, observations on history and on common factors may help efforts in other areas of biomedical engineering.

At the outset of the program, it seems to have been the consensus that the problems associated with artificial limbs were primarily engineering problems. All that seemed needed was for the surgeons and physicians to tell the engineers what kind of knee joint or artificial hand was required and for the engineers to design and build it. However, the fallacy of this concept was revealed in the very early stages when it was discovered that neither group could develop design criteria without assistance from the other. Clarification of talents each could contribute led to sound cooperation. With greater understanding, there was less risk of gadgeteering design with inadequate fundamental data. Conversely, closer touch with clinical practice reduced the danger of prolonged academic research on imagined problems before transition into trials on patients.

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[a] Research in Service to Man, Hearings before the Subcommittee on Government Research of the Committee on Government Operations, United States Senate, Ninetieth Congress, First Session, on Biomedical Development, Evaluation of Existing Federal Institutions, Feb. 28, Mar. 1, 2, 3, and 16, 1967 (83–470).

A comprehensive study of functions of the human lower extremities, for example, was undertaken by a team of surgeons and engineers in order to gain a better understanding of the functions lost as a result of amputation at various levels. Design of components was carried on simultaneously, results were compared with data accumulated in the fundamental studies, and refined design criteria were developed. Trials on increasing numbers of amputees led to frequent iteration through redesign and reevaluation until, with patience, useful items emerged.

Experience with above-knee suction sockets brought about the realization by both professions that the connection between man and his prosthesis is the foundation for any success that is to be achieved in prosthetics. The traditional skills of the limb maker were supported by increasing understanding of anatomical and biomechanical principles of fitting and alignment. At this point the "Artificial Limb Program" began to emerge as a true interdisciplinary team effort.

It was also recognized that the successful completion of a research and development project did not insure that the results would be applied to patients that needed them. In order to accelerate the introduction of new devices and techniques into application in the field, formal education programs for clinical teams were established in three leading universities. These programs have proven to be very successful and today there exists a truly coordinated program made possible by interdisciplinary teamwork.

As a result of the integrated research, development, evaluation, and education program, nearly every aspect and detail of the management of amputations and amputees has been changed. The practice of limb prosthetics is entirely different from the practice two decades ago. Prosthetists spend more time with patients and less time in lengthy manual tasks. Prefabricated parts, especially of the new designs, are very widely used.

Amputation techniques have been improved. Surgeons no longer discharge patients as soon as the wound is healed, but follow the course of the patient through fitting and training. More functional devices are available so that the patient has a much better chance of realizing his potential. Hospital time has been reduced as well as time for the total rehabilitation process. Indeed the general attitude of the medical profession toward amputation and rehabilitation of the amputee has taken on a much more positive character.

Today it is possible for the amputee to receive a temporary artificial leg in the operating room immediately after surgery and to begin ambulation the next day. It is not unusual for the patient to be discharged from the hospital before the end of the first week and receive a "permanent," or definitive, artificial leg three or four weeks after amputation. This concept in its very early experimental stages was introduced from Europe late in 1963. Teamwork on the part of surgeons, prosthetists, and engineers in the Artificial Limb Program in developing and perfecting methods of treating amputees at all levels made it possible to offer formal instruction in this technique in the spring of 1967. Now, one year later, some 150 teams of surgeons and prosthetists have been trained, and in many parts of the country fitting of prostheses immediately after surgery is routine.

For the first decade the Veterans Administration carried nearly all of the financial burden for the program. Now other government agencies, notably the Social and Rehabilitation Service and the Children's Bureau, the organizations which are responsible for rehabilitation of nonveterans, also have authority from Congress to support research, and it has been possible to expand the Artificial Limb Program to include orthotics—a closely allied field which also calls for a combined effort by the medical and engineering professions if progress is to be made. Already, a number of the principles developed in the study of limb prosthetics have been applied to orthopaedic bracing to advantage.

It is an almost universal rule that research uncovers more questions than it answers; that the more one learns about a subject, the more he realizes how little he actually knows. This generalization certainly applies to research in limb prosthetics and orthotics. With this attitude, however, it is expected that workers in these fields of biomedical engineering will gradually bring about further revolutionary improvements in the treatment of individuals with musculoskeletal deficiencies.

MYOPLASTIC TECHNIQUES [a]

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There is a considerable volume of literature relating to amputation techniques which have been or can be described as myoplasties, including more recent works by Mondry (1), Ertl (2), and Dederich (3). In none of these contributions is there any direct reference to muscle tension and most authorities now would include this as an essential part of the operative procedure.

It can be assumed that the level of amputation has been determined on the basis of a number of relevant factors, viz., pathological, anatomical, prosthetic, and most important the personal factors such as age, sex, and occupation. Amputation having been elected as the correct procedure for the patient, it is then our purpose to produce a functional organ which can be married to a modern prosthesis. This functional organ, the stump, must meet the demands of weight bearing. It must accommodate and transfer the force actions and this will be done via the socket of the prosthesis which at the present time has a fixed volume and a fixed configuration based on relevant biomechanical considerations. Accordingly, the stump must have a smooth and regular contour with minimal change in shape during the gait cycle. It should be as powerful as possible and be covered with skin, with normal sensation and with a well placed mobile scar.

To achieve these objects it would seem appropriate to consider the different tissues of the stump separately in the first instance.

The most important thing in the treatment of the skin is to insure that there is an adequacy of skin for the proposed level of amputation and to do this we must envisage the proposed terminal bulk of the stump. Those surgeons who are practiced in the technique of amputation surgery and can guess with some accuracy the terminal bulk of the stump may be in a position to delineate precisely the size and shape of the skin flaps at the beginning of the operation. Even so the inexperienced would be wise to retain a sufficiency of skin in the flaps which can be tailored to the needs of the stump at the end of the operation. The general rule will be that the ratio of

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[a] This paper was presented at the University of Miami's Postgraduate Seminar on "Modern Concepts in Surgery and Management of the Lower Extremity Amputee." The Seminar was held at the Americana Hotel, Miami Beach, Florida, December 14–16, 1967.

the base of the flap to its length will be as great as possible. In my view this ratio should never be less than one to one. In amputations through a segment of the leg equal flaps are usually satisfactory but it may be necessary in certain instances, for example, in vascular disease, to modify these flaps and in a below-knee amputation enable a larger posterior flap. In amputations through the limb segments it would seem that it is better to permit light tension to exist at the time of suture. This will enable the formation of a linear mobile scar with no distortion. In amputations through joints such as the knee and the ankle it is necessary to have the skin if anything, slightly loose. Certainly there should be no tension.

Differing views exist in regard to the treatment of the deep fascia. Dederich (3) suggests that the deep fascia should be excised, but his purpose in doing this has been to encourage an increased vascularity in stump revisions where no doubt excessive avascular scar tissue has been the rule. In other circumstances it would seem wise to raise the integument, the subcutaneous tissues, and the deep fascia as one undisturbed flap of tissue. In some circumstances it might seem appropriate to leave the deep fascia in relation to the muscles and thus allow better security for muscle sutures.

It is necessary to consider briefly the function of the muscles in normal locomotion to remind ourselves that muscle acts with maximum force when it is at a length slightly greater than its rest length, and that it acts for a very short period of time in each walking cycle. It is, in other words, essentially isometric. In the amputee where there is less muscle to do apparently more work, muscle contractions may be of longer duration thus limiting blood flow in the muscle during contraction with an earlier onset of fatigue. Furthermore, the speed of the contraction varies with the length of the muscle. Thus, in a muscle halved in its length, e.g., in an above-knee amputation, the velocity of the contracture is approximately halved and the excursion of the muscle is also reduced proportionate with its length. In the conventional amputation the belly of the muscle is cut transversely and allowed to retract with a reduction in the speed, amount, and effective range of shortening. In the adductor group, which in normal locomotion contributes to stability both statically and dynamically during lateral rotation of the thigh, muscle action following amputation is grossly distorted (Fig. 1) whereas the abductors, short and powerful as they are, are normally intact. This produces an imbalance and possibly even an abduction contracture. Certainly the gait will have a wider base, there will be a tendency to pressure in the crotch, and probably excessive rise and circumduction of the artificial limb. The hamstrings, notably two-joint muscles, stabilize the pelvis in the stance phase and decelerate the leg during swing phase. In amputation, their main purpose is to stabilize the prosthetic knee. It is, therefore, important that they should be in a position to act as powerfully as possible. It is important too that they should be in a situation to

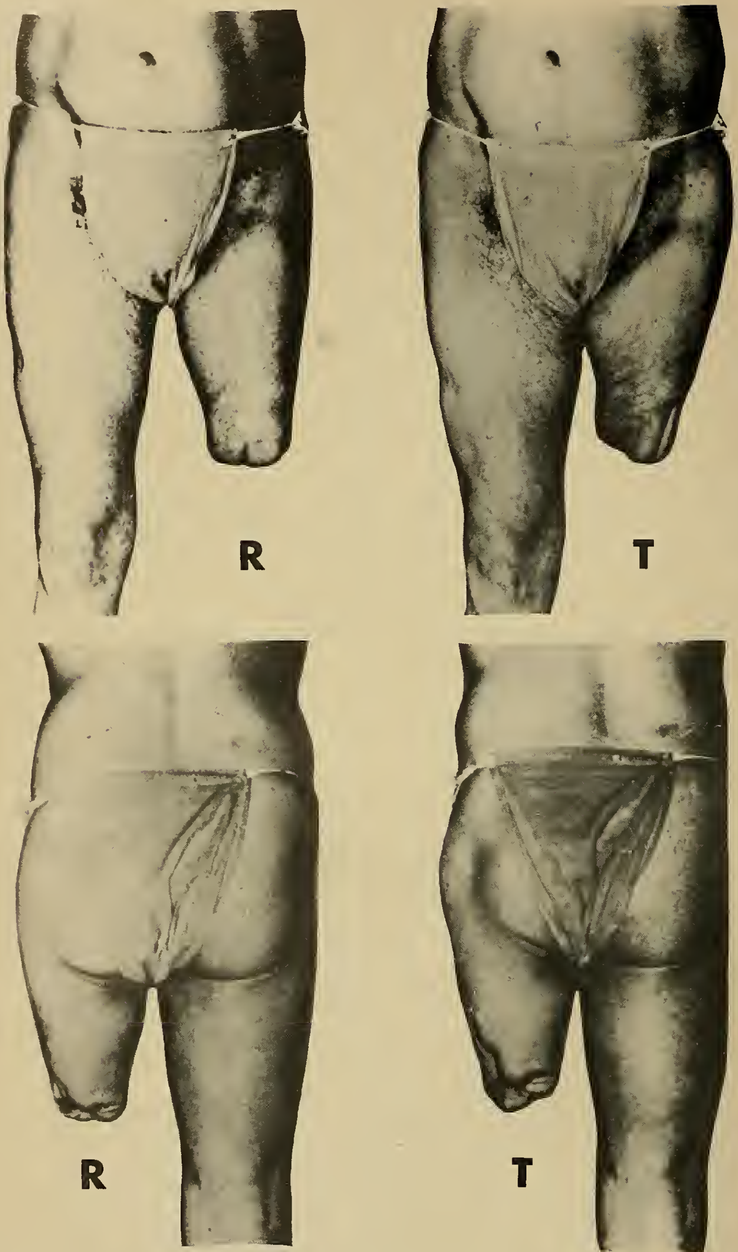

FIGURE. 1.—"Conventional" amputation. View from the front above and from behind in lower photograph. R=relaxed and T=tensed. Note distortion of scar "retreat" of muscles, prominence of femoral end at outer aspect, and marked chang in configuration of stump.

act as best as they can in order to reduce the load on the ischial seat of the prosthesis. The quadriceps bring the knee into extension and stabilize that joint in positions just short of full extension. In the amputee this function is both lost and unnecessary and the muscles act as hip flexors. They also have an isometric value as those components which are isometric following amputation will act in concert with the rectus which is now a one-joint muscle and improves the venous return and tends toward a firming of the stump, that is to say, increase its mechanical stiffness. The ilio-tibial tract, normally taut in the stance phase, helps in stabilizing the pelvis in the normal person. It is important, therefore, to preserve if one can. At the same time the shortening of the muscle following division low down in the thigh does not appear to be great and may not retreat up the stump more than one centimeter, and this is probably due to its attachment to the lateral intermuscular septum.

When a nerve is divided it inevitably forms a neuroma. If the nerve is divided at the distal end of the stump then a neuroma will form in that situation. If the neuroma gains a secure attachment to distal scar tissue, which in the conventional stump is capable of displacement, often extreme and violent during the gait cycle, then repeated, very unwelcome stimuli will be produced. It seems, therefore, correct to cut the nerve in a place remote from the end scar where it is well covered by muscle. The nerve should, therefore, be cut high. In order to do this it is necessary to pull the nerve down, but excessive tension should be avoided. In atherosclerosis it would seem appropriate to divide the nerve higher than the other tissues in any case, as Smith's (4) work in Aberdeen suggests that ischemia in the nerve trunk may reach much more proximal levels than in other tissues with an increase in disassociated nerve fibers and increased stump and phantom pain. Treatment of the nerve itself has evoked much discussion and often diverse enthusiasms. The nerve has been introduced into the medulla of the bone through windows in the cortex and has been covered in envelopes of different materials but most people would consider that a clean cut of the nerve is what is normally required. It is relevant to note, however, Weiss' (5) technique of clamping the nerve with approximately one centimeter between the clamping points and division immediately below the lower of these two points. His intention in this procedure is to produce as it were, a neuroma within the nerve. A further study will be required to see whether in fact this is a procedure of value. Burgess (6) has revived interest in ligature of the nerve because of his concern in vascular cases where the accompanying artery may be abnormally large and the cause of troublesome bleeding after a high clean cut. So far as I understand no unpleasant sequelae have followed this procedure (Fig. 2). It seems to me that the main requirement is to cut the nerve at a sufficient distance from the end scar.

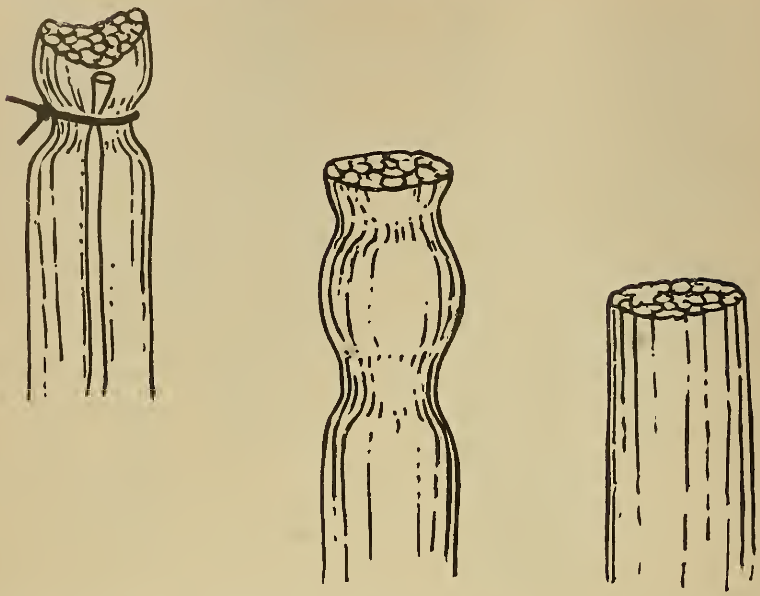

FIGURE 2.—Schematic illustration of treatment of nerve. On the left, a high clean cut; in the middle, the procedure used by Weiss with double crushing of nerve which is divided just distal to lower clamp; and on the right, ligature of the nerve where the accompanying vessel is abnormally large.

The main vessels in the limb should be isolated, ligatured, and divided low in the wound, and in this way valuable tributaries may be retained and optimum blood supply maintained.

There appear to me to be two requirements in the treatment of the bone following division. One is to shape the bone according to the needs of the particular level. In the above-knee procedure anterior smoothing and rounding should be carried out, especially in myoplastic procedures; at below-knee level, very careful sculpturing of the bone end is required to produce a smooth radius in all directions. This of course, applies mainly to the anterior distal end where the object should be to produce a large part of a small radius rather than the converse or an oblique flat plane with three corners. The second requirement is to close off the medulla of the bone, and leaving aside procedures involving the use of implants such as silicone plugs this is best achieved by a periosteal or osteoperiosteal flap. Work performed in Russia by Askalanov and Aronov (7) has contrived to show that with an open bone end the intramedullary pressure drops to zero and that the radiopaque material used in the experiments suffers a reduction in clearing time. Furthermore, the intramedullary sinuses are dilated and tortuous with residual deposits of the material. When the open end of the bone is closed again the hydrostatic situation returned to normal. Therefore, it seems that a closed system is necessary for normal intramedullary pressure to be maintained in the bone, and a normal pressure system is necessary for normal venous return from the bone. Accordingly, the medullary cavity should be closed as a definitive part of the operation of amputation.

I would wish at this point to return to the subject of the treatment of the muscles. Some of the myoplastic procedures described in the literature attempt to selectively suture agonists and antagonists over the end of the bone, but in the light of the factors already discussed this should properly be done under tension. The resultant muscle "loop" must be secured firmly to the end of the bone to optimize muscle function. If not, then the active muscle "loop" is subject to displacement with distortion of the end of the stump. Furthermore, in two patients bursae form in response to the movement of the muscle "loop" over the bone end and in one of these patients was the cause of severe pain with the development of a cavity which intermittently filled with large quantities of serous fluid (Fig. 3). Both Weiss (8) and Burgess (6) recommend attachment of the various muscle groups to the bone end via drill holes at the end of the bone (Fig. 4). This seems to be a reasonable procedure at both above-knee and below-knee levels. It tends to give a rather cylindrical stump and while I believe it to be the best technique for vascular cases, the technique can be modified and improved in respect to the shape of the functional organ we are seeking to produce. At above-knee level, I suture the adductor group, lateral hamstrings, and the medial hamstrings to the bone end via nonabsorbent sutures in approximately their proper anatomical place. This leaves the anterior half of the bone end undisturbed by drill holes (Fig. 5) and permits the use of an anterior periosteal flap raised prior to division of the bone to be brought forward over the bone end after muscle suture to close off the medulla of the bone. The quadriceps is left as one complete complex shaped at its end, and being longer than the posterior and medial muscles, is drawn over the end of the bone and sutured to these muscles posteriorly (Fig. 6). In this way we

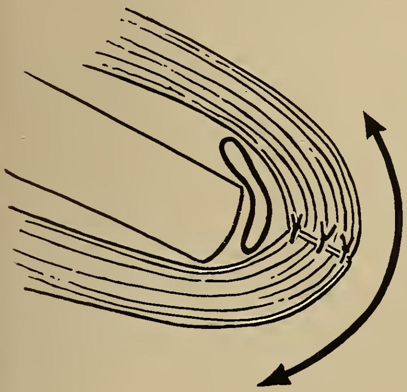

Figure 3.—Schematic representation of situation in "myoplasty" where muscle loop is formed and left unsecured to bone end; the anterior edge of the bone has not been rounded and a bursa has formed.

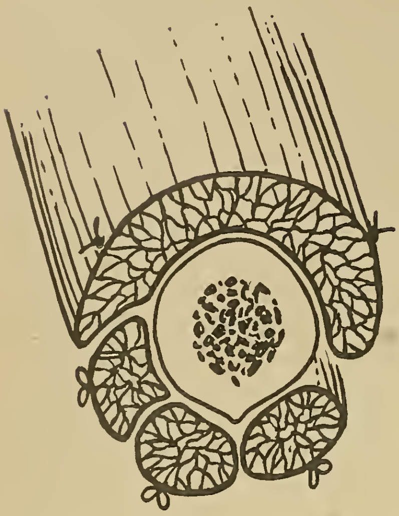

FIGURE 4.—Drawing showing management of muscle groups as in myodesis used by Weiss and Burgess; the medulla remains open.

achieve a very satisfactory stump end with smoothly changing contours (Fig. 7 and 8).

At below-knee level, I prefer to use the osteomyoplasty as described by Ertl (2) and Loon (9) where a bony bridge is formed by the raising of osteo-periosteal flaps from the medial and lateral sides of the tibia which are attached to the periosteum of the fibula thus forming a rather firm osteoperiosteal bridge. The anterior tibial and posterior groups of muscles after

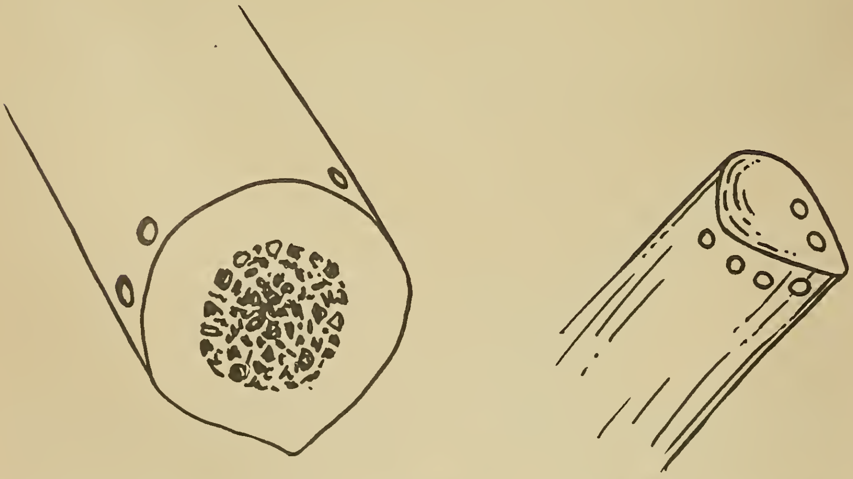

FIGURE 5.—Schematic illustration of drill holes in cut end of femur. Anterior quadrant left free of holes to permit elevation of periosteal flap.

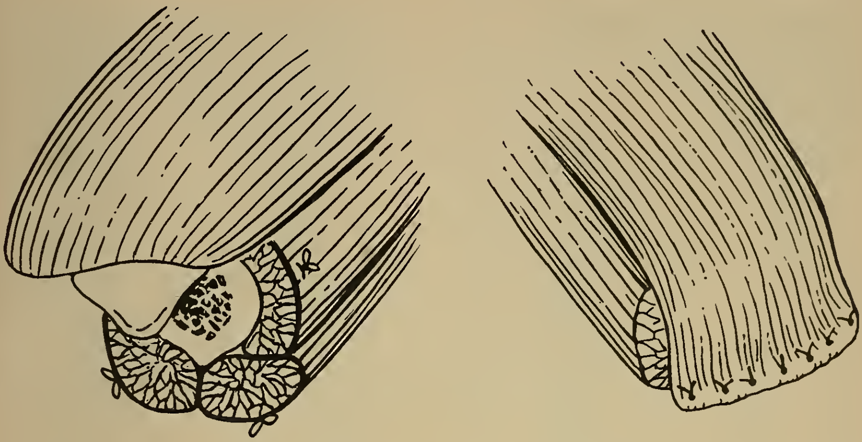

FIGURE 6.—Schematic illustration of procedure advised by author. Lateral and medial hamstrings and adductors sutured under tension to bone via drill holes and cut flush with bone end. Medulla closed with anterior periosteal flap. Quadriceps left long and drawn over stump end to be sutured under tension to posterior muscles.

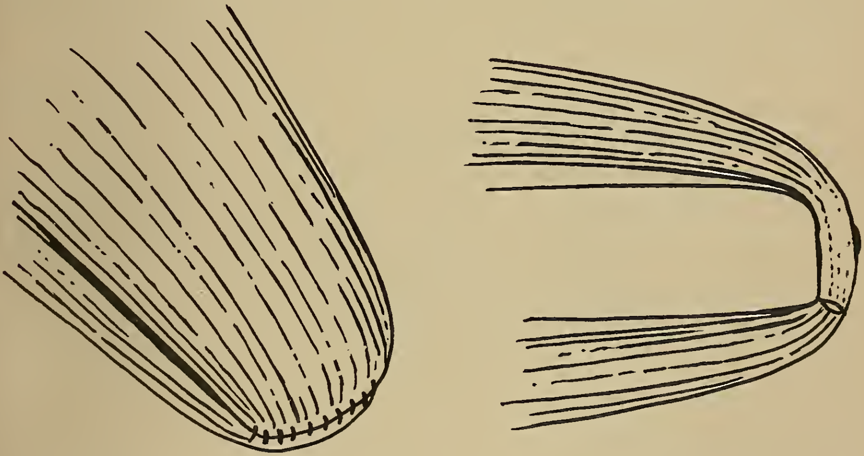

FIGURE 7.—Drawing of "ideal" situation at stump end. The posterior muscles are securely fixed to bone end. The bone is rounded; the medulla closed and the anterior muscle, e.g., quadriceps, further covers the bone and is secured to the posterior muscle groups, e.g., hamstrings. Thus an adequate but not excessive "pad" is formed at bone end, partly fibrous tissue but mostly viable functioning muscle.

trimming and possible excision of the soleus are drawn together over the bridge and sutured together. Here too, it is vital to secure the muscle loop firmly to the periosteum of the tibia and to the base of the osteoperiosteal bridge.

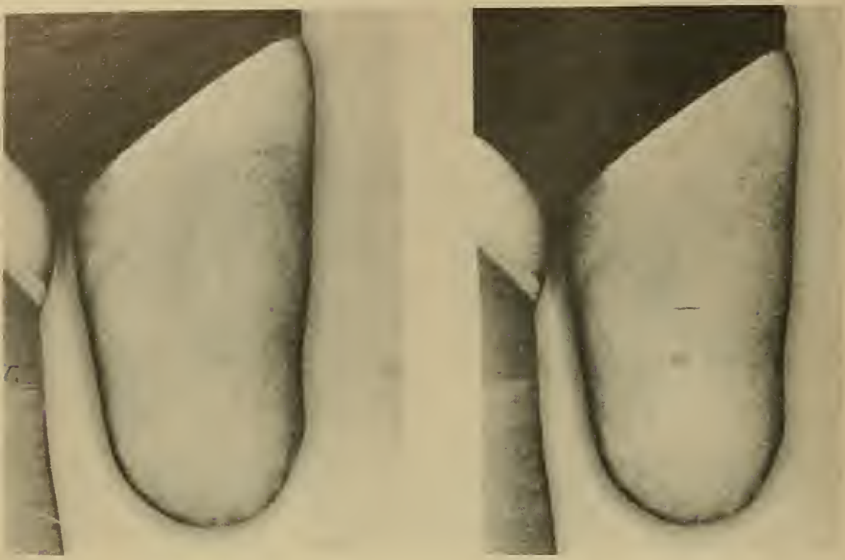

FIGURE 8.—Myoplasty amputation. Muscles secured under tension to bone end. On the left the muscles are relaxed and on the right the muscles are tensed. There is little change in shape, no scar distortion, and no muscle "retreat."

In some patients the bridge may be formed with periosteal flaps alone but this gives a rather soft saddle of tissue making muscle suture unsatisfactory. Maurer (10) employs a short section of the fibula to bridge the two bones securing fixation by an intramedullary screw. Bridging between the tibia and fibula is desirable as it stabilizes the fibula, provides better "keying" of the socket, and gives the opportunity for a degree of end bearing. In vascular cases the bridging procedures are of doubtful validity as the elaboration in tissue treatment may well prejudice healing of the wound. In these cases the technique of tension myodesis appears to be most apposite to the situation as there is no muscle or periosteal tissue left distal to the level of bone section.

Further reference must be made to the tension of the muscle at the time of suture, whether it be muscle to muscle or muscle to bone. The muscle should be sutured to the end of the stump so that the muscle is marginally shorter than it would be at rest length. Weiss (11) recommends from 0.4 to 0.8 centimeters in the case of the thigh muscles—a counsel of perfection but indicative of the thought and care being applied to these techniques. Estimation of the level of muscle division with respect to bone length can be achieved in various ways, e.g., marking sutures on the surface of the muscles and transfixion pins acting as markers or traction implements. The position of the patient at operation is of some importance. Normally this position is chosen to provide easy access for the surgeon. It is well to remember that the position chosen for operation may not be appropriate for muscle suture—in the below-knee procedure with the patient prone and the knee flexed, the limb is presented in a manner permitting convenient surgical access but full extension of the knee is required if the muscle groups are to be properly tensioned at the time of suture. I prefer to have the patient supine to insure full knee extension. In the above-knee amputation with the patient supine, a sandbag beneath the buttock on the affected side is necessary to gain sufficient hip extension for proper muscle suture. Perhaps the best position for the patient is lying on the unaffected side enabling anterior or posterior approaches and the opportunity for adequate extension of the hip.

Amputation is a procedure which has unique implications. One aspect concerns the operative exposure itself and unlike other operations it is possible to be destructive in the exposure provided this refers to the tissues distal to the ultimate level of section. The tissues remaining in the stump should be handled gently especially where nutrition is marginal, and the criteria of the procedure should be concerned with the state and relationship of the various tissues in the completed stump and not with details of exposure. In my view it is of little consequence whether the above-knee amputation is performed from the front or behind or even from the medial aspect. Equally, the below-knee procedure can be performed through an anterior approach or from the lateral aspect as advocated by Weiss (11). Our proper purpose should be to provide the best functional organ of locomotion possible in the circumstances.

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KNEE-DISARTICULATION AMPUTATION [a]

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Amputations below-thigh level and proximal to knee-disarticulation level include all the transcondylar procedures such as the Gritti Stokes (1,2) and Callender (3,4) procedures and are not considered in this contribution. In my view they are largely undesirable because they provide little end bearing, may not leave sufficient space for the inclusion of assistive devices in the prosthetic knee, and are perhaps better replaced by a long myoplasty amputation. The Gritti Stokes procedure in particular often gives rise to a number of complications most of these being due to the retention of the patella. Recent contributions suggest this operation is excellent at least in terms of wound healing. Unfortunately, it has persuaded a number of surgeons to employ the procedure for this reason alone.

We are concerned in this contribution with the through-knee amputation or knee disarticulation. At the outset I should say that there seems to me very little validity in an argument about the relative merits of operative procedures at different levels of limb ablation except in the individual case. On this basis it will be assumed that an amputation can properly be done below-thigh level but for one reason or another cannot be done at below-knee level.

The knee-disarticulation operation has a long history of use extending back to the sixteenth century if not before (5,6,7,8). Like many surgical procedures its popularity has waxed and waned with changing surgical fashion and in this particular case with the prosthetic practice of the day.

I believe the procedure has a stated place in our surgical armamentarium.

In the first place it has a particular application during the growth period as it preserves the distal femoral epiphysis and thus the capacity for 80–90 percent of femoral growth. In this way we obtain a stump of maximum length when skeletal maturity is reached yet somewhat shorter than the femur on the other leg thus allowing the inclusion of assistive devices in the prosthesis. The stump will demonstrate its other advantages; viz:

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[a] This paper was presented at the University of Miami's Postgraduate Seminar on "Modern Concepts in Surgery and Management of the Lower Extremity Amputee." The Seminar was held at the Americana Hotel, Miami Beach, Florida, December 14–16, 1967.

1. A large end-bearing surface covered with tissues adapted to this situation as in kneeling: in the adult the area is between 14 and 20 sq. in.
2. It provides a long strong lever where most of the muscles have a satisfactory status in physiological terms.
3. A bulbous end insuring rotational stability and good suspension.
4. Because of the factors mentioned, proprioception is excellent.

All these listed advantages immediately suggest the knee-disarticulation stump as of particular value to the elderly and this, I believe, is so. Once certain principles are accepted the operation is particularly suitable for the elderly atherosclerotic as the procedure is relatively bloodless with minimum division of soft tissue and can be performed comfortably in 30 minutes. In all cases of atherosclerosis requiring amputation and where this is not deemed advisable at below-knee level, the disarticulation should be given serious consideration before a thigh amputation is performed. In the circumstances found in these cases I cannot find justification for modifications such as excision of the patella or trimming of the femoral condyles, as they lengthen operative time, increase the chance of bleeding, and may prejudice the blood supply to the flap. It is fair to mention the fact that the patient with two knee disarticulations will fare better than the double above-knee amputee, with or without prostheses. This, however, is a complicated situation and other factors will influence decision in these cases.

In the young male adult the operation has much to commend it and especially in those who are particularly active, perform heavy work, or live under rough conditions.

I do not believe that it is a good amputation to perform on a young woman because cosmetically the prosthesis is not satisfactory. In these circumstances even if the pathology and other relevant factors allow a disarticulation, I would undertake a low myoplasty of the thigh.

It is a procedure which should not be done where there is a fixed permanent flexion deformity of the hip or where a below-knee amputation is feasible.

The operation is best done with the patient lying prone and the affected knee flexed. This has the additional advantage of reminding the surgeon of the importance of any existing hip flexion deformity and it also permits surgical approach to both back and front of the joint. The classical procedure requires that the anterior flap should be twice as long as the posterior flap and that the anterior flap at its lowest point will be 1 in. distal to the insertion of the patellar tendon or expressed in other terms, it is a full handsbreadth below the patella. With the knee flexed the anterior dissection continues to joint level. The philosophy of the surgery is to keep the knife close to bone and dissect up the anterior flap as one completely undisturbed hood of tissue. Where applicable the knife will dissect the tissues from the bone and in this way the front flap will contain, from the surface inward, skin, subcutaneous tissue, bursae, deep fascia, patellar tendon and patella, capsule and the muscular expansions of the front of the knee and the retropatellar fat pad. In this way the pes anserinus is elevated along with the hood of tissue insuring attachment for the sartorius, gracilis and semitendinosis, and of course the quadriceps extensor itself. Once the anterior flap has been elevated in this way and the joint exposed, the cruciate ligaments may be divided. Attention is then directed toward the posterior aspect of the extended joint, and after delineating the posterior flap which is rather short and rectangular in shape the deep fascia is divided in line with it. The heads of the gastrocnemius are isolated and divided along with the plantaris muscle. The popliteal artery and vein are easily isolated, ligated, and divided at a low level in order to preserve any useful branches. The lateral and medial popliteal nerves are pulled down gently and divided by a clean cut with the usual proviso regarding any abnormally large vessels. The biceps tendon is divided and the posterior capsule then alone remains for division. It will be recalled that the tendon of semimembranosis is inserted into the posterior aspect of the head of the tibia, the fascia overlying the popliteus, and the capsule itself, and if the capsule is divided as low as possible, then we retain the insertion of this muscle. The patellar tendon is then sutured firmly to the stump of the cruciate ligaments and the anterior muscle expansions and capsule are sutured to the posterior capsule of the joint thus insuring fixation of the quadriceps in front and the hamstring muscles behind with the exception of the round tendon of the biceps. This too should be sutured separately at rest length or slightly shorter.

In this way the joint is in effect reconstituted. Dr. Vitali (9) at Roehampton says that this is a bad practice as they have several times seen effusions in the reconstituted knee joint. I have not seen this complication but accept it as a theoretical possibility. Even so the procedure I have described is attractive from a physiological point of view as it retains the same tissue arrangement as in the kneeling normal limb thus permitting maximum end loads. Furthermore, with the practice of elevating the anterior flap and the posterior capsule in the way described, we have restored a near physiological situation for the muscles remaining in the stump.

It will then be found that suture of the skin leaves a very loose suture line. Surgeons unpracticed in this operation are advised to avoid trimming the anterior flap as once the wound has healed the looseness of the skin is not apparent; whereas, if any tension is employed at this level of operation a broad adherent scar will result. If suture of the incision requires considerable tension then inevitably high load areas will appear over the posterior aspects of the femoral condyles and skin necrosis is inevitable. There seems to be a general rule that amputations at joint levels require no tension at the suture line whereas amputations through the shafts of bone will permit light tension at the suture line. In this regard I would draw your attention to a procedure I saw recently in the Orthopaedic Hospital in Copenhagen where Dr. Knud Jansen (10) finalized the procedure with a single posterior vertical scar. This is done in a manner similar to that of Velpeau (6) by employing a roughly circular incision around the upper limit of the shank with the knee flexed (Fig. 1). The characteristics of the operative procedure are the same as in the procedure already described, but clearly, care in the geometry of the incision is required to insure neat apposition of the skin edges. This is the procedure I propose to follow in the future as it seems to me it will insure the correct skin tension over the end of the femoral condyles and with care will avoid the problems of flap length, wound tension, and possible necrosis.

Postoperative dressing of the disarticulation is in my view not so crucial as it is in amputation in the thigh and shank of the leg, but it is still my practice to apply a rigid plaster-of-paris splint whether it is an immediate postoperative fitting situation or not.

Inevitably arguments about amputation techniques always involve the prosthesis available to satisfy the resultant stump. This is particularly true of the knee disarticulation. Modifications of the procedure abound in the literature and most are directed towards reducing the size of the bulbous

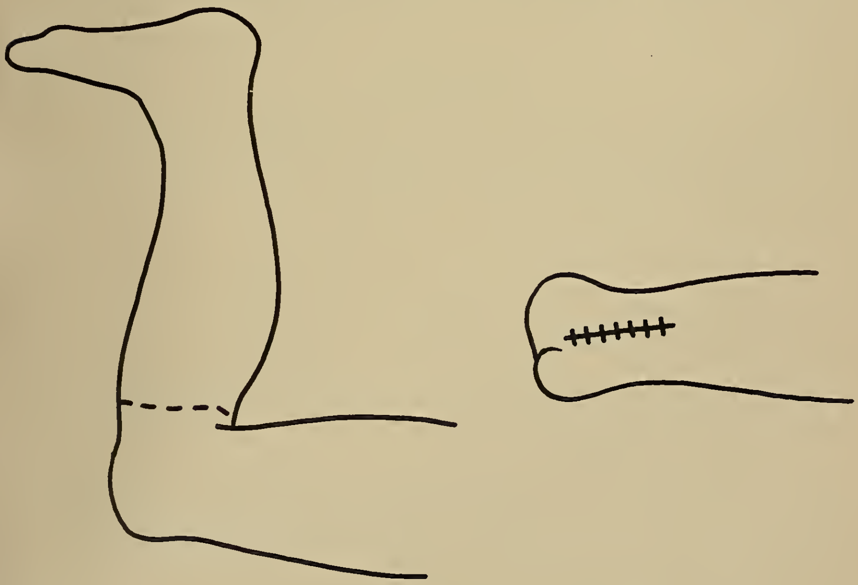

Figure 1.—Disarticulation of the knee. Patient prone and approach through roughly circular incision resulting in final vertical posterior scar (after Jansen).

end of the bone. I believe that provided the procedure is employed in the instances I have given, attempts of this kind are invalid. I am sure, too, that in the very near future, a more satisfactory through-knee prosthesis will be produced. The standard prosthesis with a combined thigh corset and socket made in leather with side steels and uniaxial joints provides a very satisfactory prosthesis for the young male adult by giving full end bearing and excellent suspension. In the elderly there may be problems as these patients often have associated disabilities such as weak, deformed arthritic hands. They may not have the capacity to lace up the thigh corset tightly enough to insure proper suspension and fit. We have been using a plastic socket embodying the same philosophy as the Canadian Syme's prosthesis. Twenty of these patients have been fitted with only two rejections so far. This type of prosthesis is only at the first stage of its development and no doubt someone will devise a socket which permits easy entry of the stump, full end bearing, and complete stability allied to ease of application. It seems to me to be largely an exercise in spatial geometry.

The approach used in the operation is not of great moment provided the principles involved in the treatment of the tissues are observed. Weiss of Warsaw, for example, performs the whole procedure from the posterior aspect, but I am satisfied he treats the tissues in the way described and the final stump is the same. I am persuaded that the technique employed by Jansen will probably emerge as the best available.

Whatever the approach the knee disarticulation has a definite place in amputation surgery with rather well defined indications.

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THE BELOW-KNEE AMPUTATION[a] [b]

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Throughout the United States and Canada an estimated 80 percent of all major elective civilian amputations result from ischemia. All but a relatively few involve the lower extremity. Significant improvements in below-knee prostheses and important advances in surgical and postsurgical management now allow amputation below the knee in a majority of patients. In a consecutive series of 96 unselected major lower-extremity amputations for peripheral vascular disease—1964 to 1967—we have been able to obtain primary healing at the below-knee level in 75 percent of the cases. Once healed, the stumps remain healed. With adequate prosthetic care, secondary breakdown will seldom occur. It is not possible to overestimate the great importance of the knee in amputee rehabilitation. This is true especially in the older, classical, ischemic patient. Debility, impaired vision and balance, neuropathy, compromised circulation and function in the remaining lower limb, together with chronic systemic illness, all emphasize the critical need to save the knee. The older bilateral leg amputee especially needs his knees to approach the rehabilitation goal permitting a reasonable degree of ambulation and self sufficiency. The below-knee amputation thus becomes statistically by far the most important major elective technique.

SELECTION OF PATIENTS

A. Peripheral Vascular Disease

When acute or chronic compromise of arterial blood supply reaches a level insufficient to support tissue viability and when reconstructive surgery and nonsurgical supportive measures fail, amputation will be required. The great achievements in surgical reconstruction of the peripheral vascular system represent a leading chapter in medical progress during the past two decades. Continuing basic and clinical research throughout the world supports the hope that an even higher percentage of limb salvage can be expected in the years ahead. As basic causes of degenerative arterial disease become better understood, prophylaxis will play an increasing role. Despite the practical effectiveness of modern vascular reconstructive surgery and the promise of preventative measures to forestall degenerative and occlusive arterial disease, statistics indicate that amputations for ischemia are increasing both relatively and absolutely in relation to population throughout the western world. Patients requiring amputation are entitled to comparable medical and surgical consideration, comparable team effort, and the same high-level rehabilitation management attending similar patients whose ischemic limbs are treated by vascular reconstruction. Too often, ablative surgery does not command this high estate.

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[a] This paper was delivered at Roehampton, London, England, November 16, 1967.

[b] Based on work performed for the Prosthetic and Sensory Aids Service under the Intra-VA Prosthetics Research Program.

[c] Director of Amputations and Congenital Defects Service, Children's Orthopedic Hospital, Seattle, Washington; Area Consultant of Amputation and Prosthetics, Veterans Administration; Associate Clinical Professor, Department of Orthopedic Surgery, University of Washington, Seattle, Washington.

Decision to amputate may be simple and evident. Gross necrosis of tissue with demarcation, uncontrollable infection, pain, irreversible neuropathy, alone or in combination with results of specific tests to assay circulation, will establish the need to amputate. When all available information poses a serious question as to the possibility of limb salvage by reconstructive surgery rather than amputation, it has been common practice to attempt such surgery, even though extensive. Before questionable extensive reconstructive arterial surgery is carried out, the surgeon should critically consider the overridding probability of its failure with mandatory subsequent amputation. Will the proposed surgery compromise the level of amputation? Will amputee rehabilitation be additionally complicated by further deterioration of general health incident to the extensive surgical attempt at limb salvage? We have, on a number of occasions, performed below-knee amputations in ischemic patients who were being considered for possible vascular surgical treatment but in whom, after review of all available information, such surgery might well have damaged existing blood supply to a degree that an above-knee amputation would then have been required. It is important that the responsible surgeon understand the great rehabilitation value of the knee and weigh all facts relevant to rehabilitation potential.

There is no single test or combination of tests now available that will specifically demonstrate the lowest effective amputation level. We have repeatedly obtained successful below-knee amputations in patients whose arteriograms indicated complete occlusion of the superficial femoral artery. A careful physical examination is then the first requisite in level determination. Tissue appearance, clinical assay of skin temperature, the presence or absence of edema after elevation, growth of hair, sensation level and acuity, together with palpation of pulses are all important and cannot be supplanted by laboratory data. Arteriography, plethysmography, thermography, and a number of other objective determinants are useful. These include skin mapping with interarterial fluorescein, the use of radioactive Xenon #133, and transcutaneous doppler recordings. Each adds to the available information and assists in level determination. Old established guidelines for determining amputation level are not valid when weighed against our recent experience. Unless it is *clearly evident* that a through-knee or above-knee amputation will be required, the surgeon should prepare the leg for both below-knee and above-knee amputation. Incisions through the skin and muscle preparatory to below-knee surgery can then be quickly carried out. Bleeding and tissue viability can then be visualized directly and the final decision now made as to the level of amputation. Only a few minutes are added to the operative time should one elect above-knee or through-knee level.

Technique for Below-Knee Amputation in Ischemia. No tourniquet is used. The leg is draped free with the patient supine. Open and infected areas are walled-off and shielded by sterile plastic drapes prior to skin preparation. The level of amputation is 3½ to 5 in. below the knee, i.e., a short below-knee stump. We routinely use a long-posterior and short-anterior skin flap. It has been recognized for many years that skin over the posterior leg has better blood supply than that anterior and anterolateral. A long anterior flap, even equal anterior and posterior flaps should be avoided. Using the long-posterior flap, the resulting anterior scar is no problem in limb fit. It is our policy in fact to place the scar wherever it will heal most advantageously. The modern total contact below-knee prosthetic socket can accept a stump with scar placement in any position, provided it is non-adherent, well-healed, and nontender.

The anterior skin flap is fashioned at approximately the level of anticipated tibial section. The posterior flap must then be 5 to 6 in. longer to provide proper skin coverage without undue tension.

After outlining the skin flaps, dissection is carried down through the deep fascia to the tibia. Periosteum is incised and stripped proximal 1 in. The anterolateral muscles are divided down to the intermuscular septum; blood vessels and nerves are appropriately ligated and severed, then the tibia and fibula are sectioned preferably with a power saw. The fibula is cut no more than ⅜ to ½ in. above the level of the tibia. Soft tissues are dissected from the posterior aspect of the tibia and fibula down to the level of the posterior transverse division of skin. The leg is then separated and removed. The tibia is very carefully rounded with a short bevel over its anterior and medial aspects. It is important that no rough bone areas or ridges remain. A long bevel is specifically avoided. Nerves are pulled down and sectioned high with a sharp knife. They are neither injected nor crushed nor cauterized. The major nerves are ligated with fine suture prior to and just above the site of division. Encircling suture controls oozing from blood supply accompanying the nerve. It also appears to localize neuroma formation and lessen overgrowth and adherence to adjacent structures. The posterior muscle mass consisting of the gastrocnemius-soleus and deep flexor group is now beveled to permit the entire muscle flap to come forward and be sewn anteriorly to the deep fascia of the anterolateral muscle group and to the reflected periosteum over the anterior tibia. Medial and lateral contouring and trimming of gastrocnemius muscle gives a smooth musculofascial flap stabilized over the end of the bones. The skin is then brought up and closed without subcutaneous suture. Medial and lateral "dog ears" are contoured moderately. They should not be taken back sufficiently to disturb skin circulation. The immediate postsurgical socket rapidly shapes the stump including moderate skin irregularity at the medial and lateral angles. The wound is drained deep to the muscle flap, i.e., to bone. Through-and-through drain or suction drainage may be used. An immediate postsurgical rigid dressing and prosthesis is then applied.

Drains are removed 48 hours following surgery. If the patient's general condition permits, ambulation with guarded weight bearing is begun 24 to 48 hours following surgery. Touchdown weight bearing only is allowed until the initial cast change. Weight in the initial prosthesis should not exceed 25 lb. until cast change. Personnel who ambulate the patient should be carefully instructed as to their responsibility in preventing the patient from bearing excessive weight or falling. However, the advantages of upright activity with limited stance and gait are obvious.

Postoperative pain is generally of a diffuse aching type. The postsurgical management with an immediate prosthesis has resulted in much less pain than previously encountered. Localized complaints of pain would indicate abnormal pressures and require stump inspection or possible socket change. Unless complications develop—i.e., evidence of infection, excessive loosening of the prosthetic cast, or severe pain—the initial rigid dressing should be left intact until the time of anticipated suture removal, usually 2 to 2½ weeks following surgery. Without anesthesia, but with sedation, the cast is removed, the wound inspected, sutures removed if indicated, and a new temporary prosthesis applied. By this time the patient is usually ready for unsupported crutch ambulation and discharge from the hospital. A temporary prosthesis is worn continuously until definitive limb fit. Ordinarily the final limb can be fabricated, fitted, and worn 4 to 6 weeks following below-knee amputation.

Necrosis of skin flaps can result either from inadequate blood supply or undue pressure. If judgment as to level has been faulty at the time of surgery and blood supply was insufficient to support a below-knee amputation, this will be evident at the initial cast change. The decision then to amputate at a higher level should be made promptly. The reamputation rate in our series to through knee or above over the 3-year period has been 9.4 percent. As experience and techniques have improved with the below-knee amputation for ischemia, our reamputation rate has continued to decrease. The surgeon would, of course, like to avoid any reamputations. However, salvage of the knee is of such paramount importance that an occasional reamputation may be required on the basis of our present inadequate diagnostic means for level determination.

B. Non-Ischemic Below-Knee Amputation

The optimum level for a below-knee amputation in the presence of adequate blood supply is at the junction of the middle and lower third of the leg. This somewhat longer stump can be well fitted with a total contact prosthesis and provides excellent leverage for strong limb control. Often, the level of amputation will be determined by the causal pathology, including infection, the degree of scarring of the tissues, and related factors. The surgeon should save all effective length down to the optimum level that is consistent with providing a comfortable nontender stump.

The elective amputation must be considered plastic and reconstructive in nature. We have repeatedly emphasized need to create a dynamic and sensory motor end-organ. The below-knee stump no longer hangs suspended in an open-end socket. Total contact with variable degrees of pressure and weight bearing over the entire stump surface enhances the surgeon's opportunity to fashion a functional terminal end-organ. Stump strength created by surgical muscle stabilization, pliable, sensitive, but nontender skin and scar, adequate soft tissue coverage of bone ends and other pressure sensitive areas, high ligation and division of nerves to remove neuromata from pressure zones, meticulous rounding and tailoring of bone surfaces all contribute to an ideal organ for substitute limb reception. As this stump matures, the profound shrinkage previously considered desirable is avoided. The atrophic, wasted, bony, below-knee stump so commonly encountered in years past is no longer acceptable.

In addition to established physical measures of rehabilitation the therapist must specifically stress exercise for stump musculature. Isometric exercises of the stump muscles sectioned at amputation level and surgically stabilized should be encouraged. A cylindrical stump shape is desired. For the purposes of teaching we direct the surgeon's thinking in terms of producing a foot-like organ at below-knee level. The total contact socket is the "shoe on the foot." Just as plastic surgical techniques are required in operating on the hand and foot, the same techniques of gentleness in skin and other tissue handling are applicable to amputation surgery. When viewed in this light, the amputation becomes a surgical challenge instead of a distressing surgical exercise. Immediate postsurgical prosthetic fitting not only supports and augments the dynamic approach to rehabilitation, it offers certain physical advantages, i.e., immobilization, appropriate continuous pressure relationships, and comfort. These benefits further justify its incorporation into the overall management of the below-knee amputee.

SUMMARY AND CONCLUSIONS

Below-knee amputation is statistically the most important major amputation used today. The vast majority of major lower-extremity amputations performed for ischemia will heal primarily and remain healed at below-knee level. The below-knee amputation for ischemia is short in length, the posterior skin and myofascial flaps are fashioned long, technique is precise. The resulting stump is cylindrical in shape, well-padded, comfortable, and easily fit with modern below-knee prostheses of the total contact type (Fig. 1 and 2). An immediate postsurgical prosthesis is an integral part of the overall below-knee amputee management in both the ischemic and non-ischemic patient. Restoration of function and rehabilitation of the below-knee amputee, both unilateral and bilateral, has improved in almost spectacular fashion when the guidelines and management which have been outlined are followed.

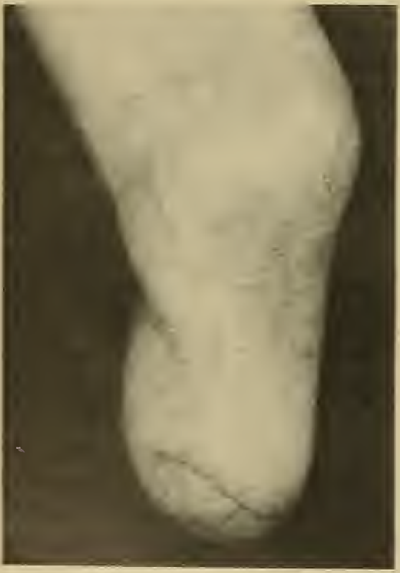

FIGURE 1

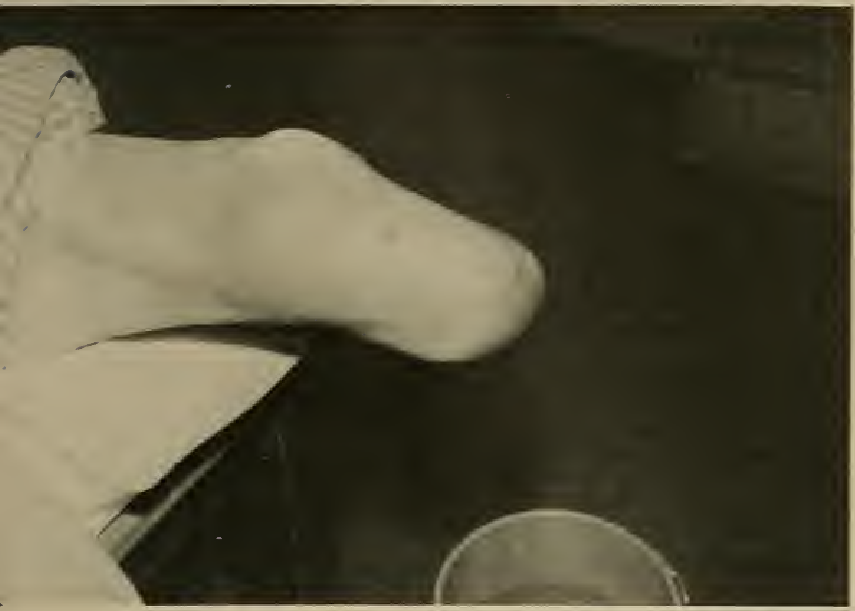

Figure 2

CONSERVATION OF ENERGY IN AMBULATION [a b c]

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Within physical and physiologic limitations, the bones and muscles are used in walking so as to achieve the most efficient pattern of locomotion. Minimal energy expenditure would be achieved if human locomotion were in a straight line; progression at a constant velocity would then require only a force sufficient to keep going and to overcome friction. However, the line of progression of the body's center of gravity is not level and the body does not proceed at a constant velocity. It appears that in walking the body is constantly converting energy from potential to kinetic and then back to potential energy again.

AUTHOR'S NOTE: This discussion is a summary of research conducted at the Biomechanics Laboratory by a number of investigators; most of the results have been reported previouly (1–12).

When we at the Biomechanics Laboratory began the study of human locomotion, we thought that measurement of all the conceivable displacements or reactions, such as angular displacements and velocity, would enable us to understand what it is that constitutes human locomotion. However, when we averaged all our findings, we found that the values did not apply to any single one of our subjects. There is no such thing as an average man. We found that our average values for the major displacements of the larger joints, such as the hip, knee, and ankle, were reasonably representative, but when we measured smaller rotatory displacements, such as the rotation of the pelvis and the rotation of the leg about its long axis, we found that these rotations, as projected in the extremity, vary from 3 to 31 deg., or several hundred percent.

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[a] Reprinted with permission from Archives of Physical Medicine and Rehabilitation, Vol. 48, September 1967. Illustrations have been added that did not appear in the original.

[b] This study was supported in part by funds from the National Aeronautics and Space Administration, the National Institutes of Health, the Veterans Administration, and the Vocational Rehabilitation Administration (and its predecessor, the Office of Vocational Rehabilitation).

[c] Presented at the Twenty-Eighth Annual Assembly of the American Academy of Physical Medicine and Rehabilitation, San Francisco, August 30, 1966.

[d] Professor and Chairman, Department of Orthopaedic Surgery: Director, Biomechanics Laboratory, University of California School of Medicine, San Francisco.

It then became important for us to try to develop a concept of locomotion that could be applied to all human beings. We assumed that each individual employs whatever nature gave him in his attempt to function with the least expenditure of energy. In walking, the bones and muscles are used, within limitations imposed by the laws of physics and the laws of physiology, to achieve the most efficient pattern of locomotion.

I believe that this assumption has been confirmed in our later studies. Therefore, I would like to approach the problem from the standpoint of energy levels and the shift of energies back and forth in the extremities. It is perfectly obvious that minimal energy expenditure would be achieved if human locomotion were in a straight line; progression at a constant velocity would then require only a force sufficient to keep going and to overcome friction.

To achieve progression, however, force must be exerted on the object and must work against a fixed point, because for every force there is an equal and opposite force. If we examine patterns of human locomotion, it becomes evident that in this case the opposite force is the instantaneous reaction from the floor. First, what happens to the body as a whole can be determined by means of floor reactions as registered on a force plate, which records the instantaneous vertical loads, fore-and-aft shears, lateral shears, and torques.

The force-plate data show that as the heel strikes, the reaction from the floor increases, and that for parallelism, as the foot is loaded, a little more than body weight is carried. This occurs as a result of the impact of the foot on the floor. Then the center of gravity of the body starts to descend as it passes over the weight-bearing leg, and as this happens the force plate records less than body weight; in the next few instants, the value drops to as little as about 40 percent of body weight. This happens because the knees are bending and the ankles are plantar flexing. Then, at the time of push-off of the foot from the floor, the force plate again shows increasing load, indicating that, as the body is elevated, the floor reaction is greater than body weight.

A recording of this type indicates that people bounce up and down when they walk. Since the line of progression is not level, the question immediately arises of what would be the most efficient displacement pattern. Mathematically, it would be a sinusoidal curve, and this is precisely what we found—when vertical displacement is measured, the average curve follows approximately a sinusoidal path.

Force-plate records of fore-and-aft shears demonstrate that as the foot strikes the ground there is a negative shear (backward thrust), as the body passes over the leg the shear becomes neutral, and at push-off there is a positive shear (forward thrust).

This means that, in the first part of the phase, the foot is being pushed forward against the floor by the body, while, in the last part, the foot is pushing against the floor to move the body forward. Furthermore, direct measurements of the forward progress of the body substantiate the force-plate recordings—human locomotion does not take place at a constant velocity, but moves faster at one point and slower at the next.

Is it possible that the body in locomotion, because it is moving up and down and because it is varying its horizontal velocity, is converting energy from potential to kinetic and back to potential? It appears that that is precisely what happens.

The proportionate energy transfer will be discussed later in the paper.

But there is another problem. During the double weight-bearing phase there are two shears on the floor: a backward thrust of one leg with a forward shear on the floor, and a forward thrust of the other leg with a backward shear on the floor. This situation results in a force couple that acts on the pelvis and causes it to rotate first in one direction and then in the other. The changes in pelvic rotation occur during the double weight-bearing phase when each leg can contribute to the force couple. Whether certain muscles, either in the trunk or in the leg, may also be active in contributing to this pelvic rotation is, at present, not clear.

Since the forward velocity of the body is increasing during the latter half of the stance phase of one leg, while the other leg is swinging forward to be decelerated to almost zero velocity as it strikes the floor, the question is: How much of this forward force is due to the push-off—and how much is due to the deceleration of the swinging leg?

Electromyograms of muscles of the calf, when the individual walks at 75, 95, or 120 steps per minute, show very little increased activity, which is surprising. The question is: Where does the energy come from to increase the forward speed of the body, if not from a more forceful push-off? It comes from deceleration of the swinging leg. Our calculations indicate that this relation is about five to eight; that is, while five units of work are the result of the push-off, deceleration of the swinging leg contributes eight units. This explains two things. An increase in velocity does not require any increase in output from the calf group of muscles because the deceleration of the faster-moving leg provides the needed increased energy.

This phenomenon explains a common problem encountered in fitting prostheses to amputees. If a prosthesis is too light, the amputee usually does not like it. Most artificial legs feel very heavy to the average person, and a natural reaction is to inquire how the amputee can walk with such a heavy prosthesis. But, if there is too little weight in his prosthesis, the amputee develops less kinetic energy at the end of swing phase to be fed back into the body to maintain his forward velocity. On the other hand, if a leg is too heavy the initiation of swing requires more energy. So there must be a compromise. Ideally, the leg should be light when the swing phase starts, and it should be heavy toward the end of the swing. As yet, no prosthesis that has a changing mass has been developed. A good compromise weight can be calculated so the prosthesis will not be too heavy to start the swing, and yet will not be too light to feed back energy into the system. We have found that an above-knee prosthesis should weigh approximately 13 to 14 lb.

Energy expenditure has been mentioned briefly earlier in this paper. In order to provide an accurate analysis of human locomotion, it is necessary to combine knowledge gained from studies of energy expenditure with knowledge gained from the force-plate studies.

When engineers discuss energy, they analyze it purely from a mechanical standpoint, and they state that an individual, moving from one point to another and ending at the same elevation, exhibits no change in mechanical energy level even if he runs up and down or down and up a hill. He has done no extra mechanical work (Fig. 1).

The engineer's concept of energy is inadequate to explain the work done by man as a machine because man is also a biologic organism, and movement of his parts requires muscle energy, which requires that oxygen be consumed. We, at the Biomechanics Laboratory, decided to combine studies of the engineer's concept of energy with metabolic studies, in which expired air was sampled for its carbon dioxide content, and oxygen consumption was examined. Results were expressed as energy expended, or calories required per meter when walking at a fixed speed. If the value for energy expended by one individual is divided by his body weight, a value is obtained which can be compared with that for other individuals.

But an interesting phenomenon is observed: If an individual is walking at a low speed, the energy expended per step is relatively high. At a slightly faster walk, the energy used per step lessens, and finally, at a certain rate of speed, perhaps 4.5 km. per hour, a minimum of energy is used. If the subject walks faster, his energy requirements increase again. This fluctuation of energy requirement is quite characteristic of all individuals, men or women.

An amputee walking on a treadmill shows exactly the same pattern of energy expenditure as a normal individual. If the amputee is wearing a pylon, the energy curve is elevated slightly, but it still has a minimum, with

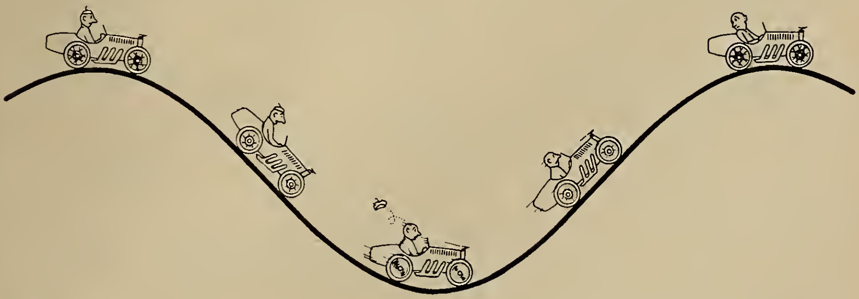

FIGURE 1.—If friction is ignored, no mechanical work has been done because the kinetic energy lost is equal to the potential energy gained.

a sharp rise immediately after the minimum because the pylon has no foot and the amputee therefore, has to climb "out of a hole," which requires additional energy. An individual on crutches will provide the same type of curve. The speed that is adopted by an individual as his most comfortable speed is that at which walking requires the minimal energy per step.

The basal metabolic rate is about 18 calories per minute per kg. of body weight. At zero velocity, that is, with the person standing still, we find that the rate rises to about 21. Walking at a normal pace requires about one and one-half times that, and walking with crutches requires almost three times as much energy.

How can the body integrate its activities and shift mechanical energy back and forth so the most efficient speed is unconsciously adopted? How much conversion back and forth between kinetic and potential energy is provided by the swinging legs and the changing velocity of the body in its forward progression with its up-and-down motion?

Some interesting relationships have been established. If the change in forward velocity is plotted as velocity squared, the curve produced is 180 deg. out of phase with the curve produced by plotting the vertical displacement of the body. If these curves are added algebraically, a curve is obtained which indicates the amount of energy conserved by this transfer (Fig. 2). Approxi-

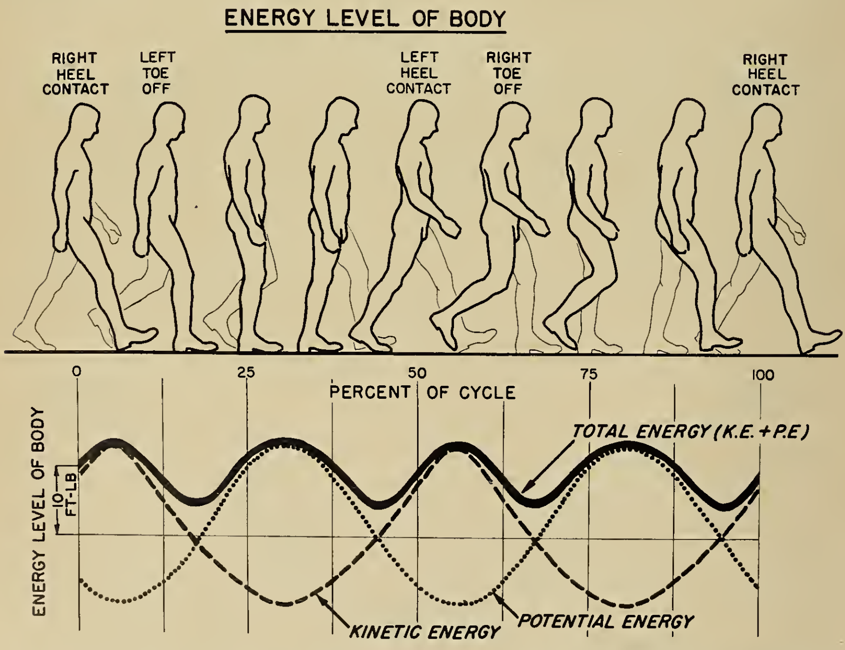

FIGURE 2.—Curves of kinetic energy (forward velocity) and potential energy (vertical displacement) of the body are shown in relation to percent of the walking cycle. The total energy curve is obtained by algebraic addition.

mately 50 percent of the required total energy is transferred (and thus conserved). This explains why it is easy to walk down a slight grade and why it is difficult to walk up it; when walking up a hill, a person raises his body a certain amount. Because of the slope, the body does not fall as far with each step as it is raised. Thus, there is no opportunity to recover as much of the potential energy and convert it into kinetic energy, so even a slight gradual slope requires additional work (Fig. 3). Interestingly enough, there is a linear relationship between grades and energy requirements (within the limits of slopes between +4 and −4 deg.). If the grade is twice as great, the energy requirements are twice as much, indicating that this relationship is probably a mechanical one and not based on any obscure, esoteric physiologic function. What happens when a person walks downhill? Just the opposite curve is produced. Here the center of gravity is raised, and as a person steps forward there is greater potential energy to be transferred into kinetic energy; energy is being fed into the system (Fig. 4).

Now, if we calculate the energy levels of every segment, including the foot, the knee, the thigh, the torso, the arm, and the head, we come out with a very complicated graph. The HAT (head + arms + trunk) rides up and down in the sinusoidal curve of vertical displacement. The curve of the kinetic energy due to the changes in the forward velocity of the body is 180 deg. out of phase. If we summate these curves, the result is a HAT total that is almost a straight line, with a slight elevation indicating change in energies when weight is transferred from one foot to the other and when the rotation of the pelvis begins to shift (Fig.

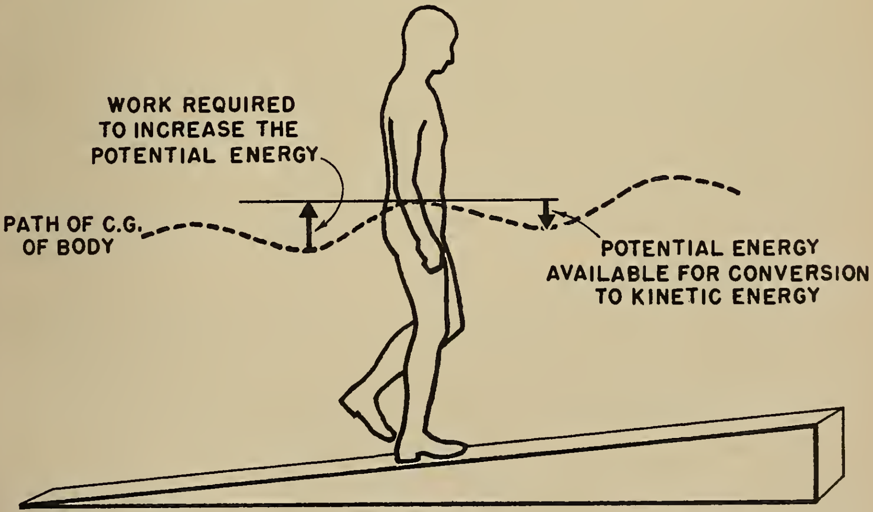

Figure 3.—Less potential energy is recovered during walking up a slope; therefore, additional work is required in order to move the body at the same velocity.

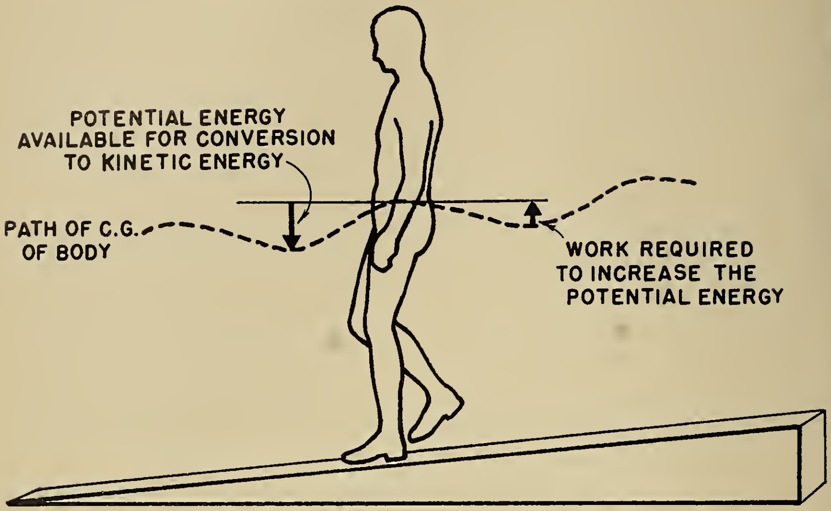
POTENTIAL ENERGY AVAILABLE FOR CONVERSION TO KINETIC ENERGY
PATH OF C.G. OF BODY
WORK REQUIRED TO INCREASE THE POTENTIAL ENERGY

FIGURE 4.—Walking down a hill causes additional potential energy to be fed into the system. A greater velocity can be achieved with the same amount of work.

5). But it looks to us now as if we are carrying head, arms, and trunk more or less as a flywheel, simply so we can convert the energy back and forth. The body above the umbilicus is not contributing anything to locomotion except by its weight.

An individual who walks very slowly rotates his thorax and pelvis in phase, but as speed is increased, rotation of the thorax gradually shifts until it is 180 deg. out of phase with the rotation of the pelvis and the swing of the legs. This is, we believe, a purely passive motion because electromyographic studies of abdominal musculature do not reveal electrical activity sufficient to account for this displacement This phenomenon acts as a damping mechanism to decrease pelvic rotation and is simply due to the passive linkage of the spinal ligaments and some of the tissues of the abdomen. It requires no muscle effort and contributes nothing to locomotion.

We also have investigated what happens to the total energy pattern when some of the motions of the body are eliminated. To achieve the transfer of energies, there must be a smooth displacement vertically, with relatively smooth acceleration and deceleration of the body. We found that immobilization of subjects in braces or casts always causes energy expenditure to increase, generally 10 to 15 percent. An individual in a rigid brace will strain in an attempt to produce counterrotation of the pelvis and the shoulders; complete immobilization of the shoulders not only produces awkward gait, but increases energy expenditure by about 16 or 17 percent.

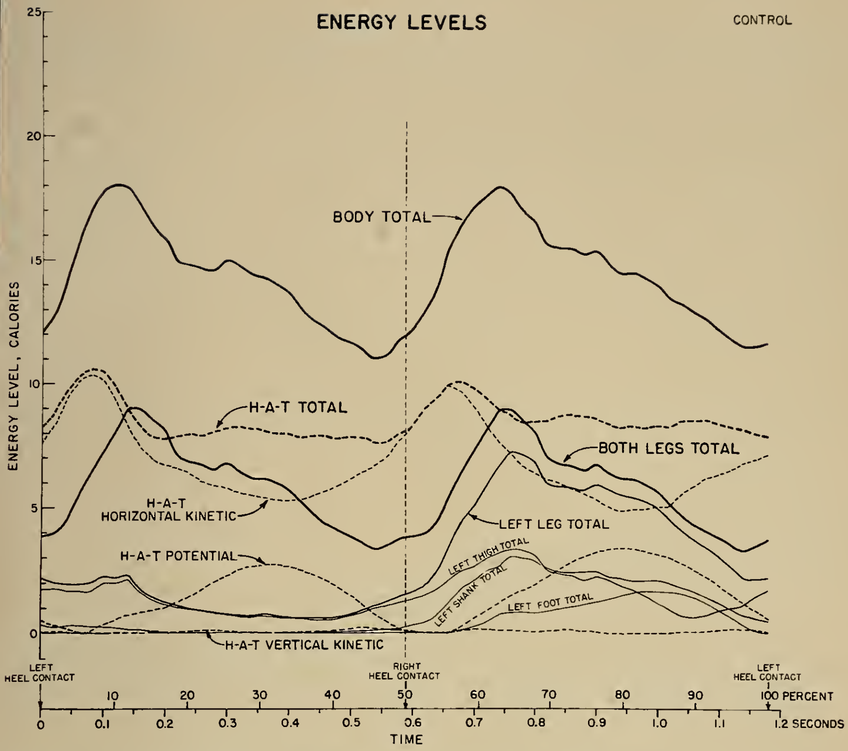

FIGURE 5.—Kinetic and potential energy levels of various segments of the body, measured at 0.02 second intervals during one walking cycle.

Now we have demonstrated that, in general, the body above the umbilicus contributes very little to locomotion. This can be proved by loading experiments. It requires 40 to 50 lb. of weights added to the belt to increase energy requirements by more than 16 percent; an individual can carry a considerable amount of weight at or above his center of gravity. Lifting this added weight requires a little increased energy, which is recovered as the weight is lowered again.

If the weight is placed in other areas, the effect is different, but, in general, if the load is placed on the HAT it does not require much increased energy to walk on the level. Of course, changes occur in uphill or downhill locomotion. It appears that most of the energy that is still unaccounted for (remember that a summation of the potential-kinetic energies produced a curve that goes up and down) is caused by the oscillation of the legs. A summation of all the various swings of the right and of the left legs produces a curve which is similar to the earlier curve. This is almost entirely due to acceleration and deceleration of the swinging leg. At the present time, it appears that the transfer of energy from HAT to legs conserves about 50 percent of the total energies required, but that there is no way of delivering to the legs this other 50 percent that is necessary to accelerate and decelerate them except by muscle action.

In conclusion I should like to point out that nature doesn't care very much how an individual walks. Nature's goal appears to be to try to get us from here to there most efficiently, with the least expenditure of energy. This is accomplished by giving us a small sinusoidal displacement vertically and oscillating our velocity in the line of progression. In this way we can convert potential energy to kinetic energy and save about half the energy that would be required if this did not occur. Anything that upsets this mechanism or disturbs this beautiful, smooth displacement pattern causes an increase in energy expenditure. And, on the average, immobilization of any segment or joint of the lower extremity by braces, casts, or arthrodesis, will require about a 10-percent increase in energy expenditures.

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PROSTHETICS ADVANCES SPEEDING RECOVERY OF AMPUTEES [a]

American veterans of the Vietnam war who have suffered amputations have far better prospects for quick recovery and rehabilitation than their predecessors in any previous war. New and increasingly sophisticated limb prostheses and revolutionary techniques for applying them are materially shortening the time that must elapse before amputees can return to normal life.

The dramatic progress that has taken place in the last 20 years in the management and rehabilitation of amputees stems directly from the work of the National Research Council's Committee on Prosthetics Research and Development. The genesis of the committee goes back to the closing days of World War II when the Surgeon General of the Army, dismayed by the primitive quality of prosthetic devices available to wounded veterans, the limited amount of industrial effort in the field, and the entire absence of research and development, turned to the National Research Council for assistance. The Council established a board with two committees, one for artificial limbs and the other for sensory devices to aid the blind. The board launched a two-fold attack on the problem, one effort directed toward immediate applications in the form of new and more efficient artificial limbs. With some administrative and functional permutations, the board has continued its efforts during the intervening years and is presently known as the Committee on Prosthetics Research and Development (CPRD) under the Division of Engineering of the National Research Council.

EXPANDED TO NON-VETERANS

Although the plight of the young veteran returning from war stimulated the initiation of the Prosthetics and Orthotics Program, it was the intent of those who created it that any benefits that might accrue should be made available to all who would be in need of them. In addition to disseminating results so that they may benefit all, whether military veteran or not, the program has been expanded to direct attention to the special problems of infants, school-age children, and geriatric patients.

Fiscal support originally came from the Office of Scientific Research and Development. Soon after the end of World War II the Veterans Administration assumed responsibility for support of the program. In the mid-1950's the Office of Vocational Rehabilitation (now Social and Rehabilitation Service) and the Children's Bureau received authorization to support research in limb prosthetics and orthotics (orthopaedic bracing) and today all three government services support the activities of CPRD.

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[a] Reprinted with permission from the "News Report" (NAS–NRC–NAE), XVIII(1):2–5, Jan. 1968.

Throughout the United States there are approximately 35 research and development projects in prosthetics and orthotics nearly all of which are supported by the Federal government. It is the responsibility of CPRD to correlate and coordinate the work of these projects, to advise its sponsors in the conduct of programs they support, and to disseminate information through the journal Artificial Limbs, the Inter-Clinic Information Bulletin, and special publications as appropriate. In addition, CPRD advises the Veterans Administration on its projects concerning sensory aids. Every effort is made to keep informed on work being carried out abroad as well as in this country. The committee enjoys an especially close relationship with research groups in Canada.

Through the work of the committee there has been established an orderly process for decreasing the time normally required between the conception of a device or a technique and its application to a patient—the phases in the process being fundamental studies, development, evaluation, production, education, and clinical application. Thus results of the program are based on a sound analysis of the musculoskeletal system, and the clinic team is prepared to meet the needs of individual patients.

LIMBS FITTED IMMEDIATELY

As a result many new devices and techniques are now available for clinical use. Among a host of items emanating from the program are improved sockets for all levels of amputation, control units for artificial knees based on hydraulic principles, easier fabrication methods, and new surgical techniques. Application of the new devices and principles results not only in improved function, comfort, and appearance of the patient but also in reduced costs of providing rehabilitation services to amputees and others with musculoskeletal disorders. A dramatic recent example of what can be done is the case of a young schoolteacher who expected to lose 6 months from his job because of an amputation below the knee. Instead, he was fitted with a temporary limb immediately after amputation and while still under anesthesia (Fig. 1). He was allowed to begin ambulation the next day and returned to a full schedule of teaching 17 days after admittance to the hospital.

These accomplishments could be made only because of excellent teamwork between the engineering and medical professions. Indeed, the Prosthetics and Orthotics Research Program, as the effort is often called, is considered to be one of the pioneering efforts in the now popular field of bioengineering.

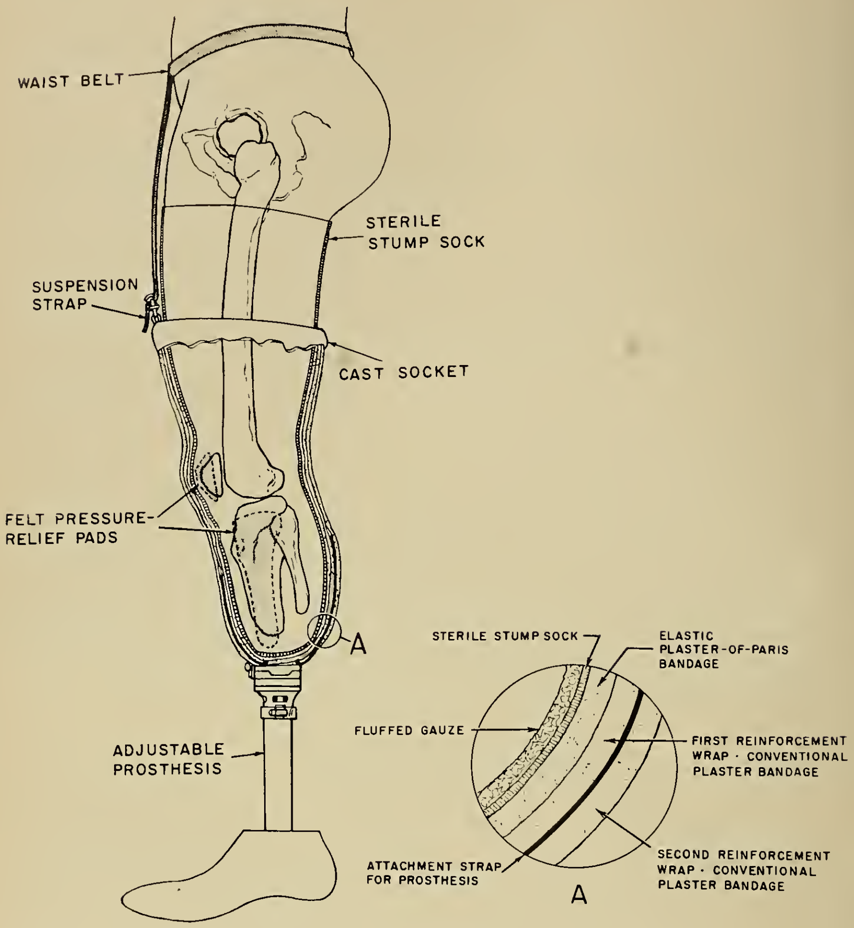
WAIST BELT
STERILE STUMP SOCK
SUSPENSION STRAP
CAST SOCKET
FELT PRESSURE-RELIEF PADS
A
ADJUSTABLE PROSTHESIS
STERILE STUMP SOCK
ELASTIC PLASTER-OF-PARIS BANDAGE
FLUFFED GAUZE
FIRST REINFORCEMENT WRAP · CONVENTIONAL PLASTER BANDAGE
ATTACHMENT STRAP FOR PROSTHESIS
SECOND REINFORCEMENT WRAP · CONVENTIONAL PLASTER BANDAGE
A

Figure 1.—Cross section shows most of the elements of the application of prothesis to a below-knee amputee immediately after surgery.

The leaders in the early days of the program soon recognized that for the results of research to be effective on a broad basis some means would have to be established for an orderly introduction of devices and techniques into the field. In 1953 a pilot education program of short-term postgraduate-type courses was set up at the University of California, Los Angeles, for clinical teams consisting of surgeons, physicians, therapists, and prosthetists. So well received was this effort that similar programs have been established within the medical schools at Northwestern University and at New York University. The postgraduate courses are now supplemented by two- and four-year courses for the training of young people to be prosthetists and orthotists.

FORMED EDUCATION COMMITTEE

To encourage the introduction of prosthetics and, later, orthotics into the curricula of physical and occupational therapy schools, undergraduate medical schools, and residency programs for orthopedic surgery and physical medicine and to help disseminate information to practitioners, the National Research Council in 1958 established within the Division of Medical Sciences a group that is now known as the Committee on Prosthetic-Orthotic Education.

This committee has been active in pinpointing educational needs in prosthetics for various health groups. It also evaluates educational materials on the subject and stimulates the development and distribution of additional education information.

Over a 2-year period ending in the fall of 1963, the committee, in cooperation with the member facilities of the American Orthotics and Prosthetics Association, conducted a survey that collected data on more than 12,000 new amputees from all 50 states. One of its findings was that below-knee amputation was performed in 2,431 cases of disease of the lower extremities in patients over 40 years of age (most of whom had peripheral vascular disease). The data indicated that the incidence of reamputation in successfully fitted below-knee cases was almost zero. This was despite the fact that many surgical textbooks warned against below-knee amputation in cases of gangrene due to vascular disease because of the supposed likelihood of reamputation. Thus the relatively large number of amputees that had been successfully fitted at the below-knee level threw doubt on the validity of the textbook principle.

The study also found a wide variation in the proportion of above-knee to below-knee amputations in different large metropolitan areas, apparently due primarily to differing philosophies of proper practice.

EMPHASIZES SAVING KNEE JOINT

In view of this kind of evidence and because of the many advantages of preserving the knee joint, the committee has been trying to encourage the practice of amputating below the knee rather than above in cases in which there are not other overriding factors.

To help carry out its work the Committee on Prosthetic-Orthotic Education has established five subcommittees in the areas of educational materials, prosthetics clinical studies, orthotics, special education projects (working with prosthetists and orthotists), and paramedical education (working with nurses, physical therapists, and occupational therapists).

These two NRC committees, whose efforts complement each other, are pioneering across a broad front to give new hope and new usefulness to those suffering from musculoskeletal deficiencies.

CLINICAL EVALUATION OF THE CETRONE BELT

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INTRODUCTION

The Cetrone Contoured Support Belt developed by the Westchester Belt Company was submitted to the Prosthetic and Sensory Aids Service for evaluation and possible inclusion on the list of approved devices for issuance to veteran beneficiaries. As a first step, the belt was examined by the Bioengineering Research Service of the Veterans Administration Prosthetics Center (BPR 10–5, p. 146; BPR 10–6, pp. 266–269). They then fitted the device to a group of five patients. Based on the finding of their limited trials, the BRS stated that . . . "The Cetrone Belt seems to offer significant advantages over corsets and braces in the treatment of acute symptoms of low back syndrome, particularly where the pain is referred to the sacroiliac area. While the Cetrone Belt does not seem to offer any clear-cut therapeutic superiority, its potential advantages relate to increased comfort, reduction of inactivity and lost time, and economy." A clinical evaluation study was recommended. This was undertaken by the Research and Development Division, Prosthetic and Sensory Aids Service.

DESCRIPTION OF DEVICE

The originally submitted belt, the one tested by BRS, was constructed of 1¾-in.-wide top grain cowhide leather with a two-pronged metal buckle. Based on the recommendations of the Bioengineering Research Service the belt was redesigned and fabricated of a double layer of 1-in.-wide Dacron webbing. Two reinforcing pads, sandwiched between the layers, fit under the iliac crests and serve as anti-slipping pads to prevent the belt from riding up. Closure and adjustment were by means of Velcro fasteners. Three sizes of belts were considered adequate for the majority of individuals. Each size belt was adjustable over a hip size range of 6 in. The redesigned belt was used in the clinical evaluation study.

EVALUATION PROCEDURE

Eight stations were invited to participate in the study and each was requested to select three patients who had a history of low back pain syndromes but were otherwise in good health. Their low back syndromes did not have to be in an acute stage at the time of selection, although this situation was preferred. The participating stations were:

VAH, Atlanta, Ga.
VAOPC, Boston, Mass.
VAH, Houson, Texas
VAH, Kansas City, Mo.
VAOPC, Los Angeles, Calif.
VAH, New Orleans, La.
VAH, San Antonio, Texas
VAH, Seattle, Wash.

Two of the stations (Kansas City and Los Angeles) were not able to select any candidates for the study, who, they felt, could benefit from the Cetrone Belt.

Three test instruments were prepared for the study and were to be completed and submitted as indicated below (see appendices):

Form CB–1 provided background information concerning the subject and was completed at the time of his selection.

Form CB–2 was the follow-up report and was completed after the subject had worn the belt long enough to determine whether or not it had been effective.

Form CB–3 was completed by the participating physicians at the conclusion of the study (i.e., when all CB–2 forms had been completed).

MEDICAL BACKGROUND DATA

Participating stations were able to select only eleven patients who for medical reasons might possibly have benefitted from wearing the Cetrone Belt. Table 1 presents basic data relating to age, height, weight, and condition and type of appliance worn by these 11 patients at time of selection. Seven of the patients were in an acute stage at the time of selection. All of them had had back problems for at least 5 years and during the prior 12 months had suffered from 3–6 attacks, except for one patient (#6) who indicated that he suffered from back pain almost continuously. Seven of the patients indicated that they wore a support routinely. Six of the seven indicated that their support was effective in relieving back pain; the seventh felt that the corset limited motion excessively. Five of the seven considered their routinely worn support comfortable. One said that it was comfortable

TABLE 1.—*Background Data*

Case No.	Age	Height (In.)	Weight (Lb.)	Condition	Orthopedic appliance used previously
1	43	68	190	L5 disc involvement	Lumbosacral corset
2	47	69	170	Chronic lumbosacral and left sacroiliac joint strain	Lumbosacral corset
3	50	68	186	Acute lumbosacral sprain with limitation of flexion	Lumbosacral corset
4	48	71	170	Low back pain (post fusion)	Walter Reed spinal brace
5	43	68	165	Low back and right hip pain (sacroiliac instability) Post op disc L4–L5	Lumbosacral support with steel stays
6	47	71	147	Ankylosis—sacroiliac joint	None
7	54	73	180	Chronic lumbosacral strain, possible HNP L4–L5 on right	None now, patient wore a lumbosacral corset but because of inguinal hernia discontinued wearing it
8	49	68	156	Low back strain	Lumbosacral corset
9	32	69	210	Chronic sacroiliac strain	None
10	68	62	117	Degenerative arthritis of cervical and lumbar spine	None
11	62	70½	192	Degenerative joint disease of entire spine	Has used a chair-type back brace and also lumbosacral belt, but not for past few years

except when sitting or driving an automobile. The seventh stated that the brace was too rigid and therefore uncomfortable.

RESULTS AND DISCUSSION

Each of the patients was provided with an appropriately sized Cetrone Belt. Patient #6 who had never worn any type of support in the past was also issued a more conventional sacroiliac support. One patient (#10) required a small size belt, two (#1 and #9) required large-size belts, while the remaining eight used the medium size belt. No set time was established for submission of a follow-up report. The patient was to wear the support until such time as he and the medical staff were able to judge if wearing the support had been of value or not. Patient reactions as to effectiveness, comfort, adjustability, comparison with other devices worn, and any other comments which were considered significant were collected during the follow-up interview. These data are presented in Table 2. Six of the eleven patients (#1, 2, 6, 7, 9, 11) reported that the support was ineffective, one patient (#10) indicated that he found it beneficial when lifting objects, while four patients (#3, 4, 5, 8) considered the belt generally effective.

Except for three of the patients (#1, 2, 10) who had some slight reservations, all rated the belt as comfortable. Adjustability was considered satisfactory by all of the wearers. Several of the patients indicated that they believed the belt would have been more effective and more comfortable if it were wider.

From this relatively small sample, no clear cut pattern of acceptance or indication can be drawn. Patients with the "same" diagnosis differed in their opinion of the device's effectiveness, some reporting favorably, others unfavorably. Those who found the device effective also found the device more comfortable than other devices. Patients who did not benefit from the belt usually indicated that their previously worn support was more comfortable. All of this obviously reflects the individuality of people and their medical problems.

SUMMARY

Two significant conclusions can be drawn from the study. It has been demonstrated that for a few patients the Cetrone Belt is at least as effective as the more conventional type of support. When medically effective its small size and low cost enhance its overall desirability. It probably, therefore, should be considered by physicians when prescribing supports.

On the other hand the total number of patients for whom this type of support is indicated is probably small. The eight VA stations selected to participate in this evaluation were able to prescribe the support in no more than eleven cases over a 6-month period. Several of the prescribing physi-

TABLE 2.—*Patients' Opinions of Cetrone Belt*

Case No.	Effectiveness	Comfort	Adjustability	Comparison with other devices worn	Other
1	Not effective	Fair—except developed rash in hot weather	Good	Not as effective	
2	Not effective, does not relieve pain—increased pain over sensitive area	Comfortable except for tender area in back	Excellent	Prefer lumbosacral corset which gives more support and is more comfortable	Could not tolerate for over one week at a time due to increase in pain over senstive area of back
3	Relieves pain	Good	Very good, would like greater adjustment range for weight fluctuations	More comfortable	
4	Relieves leg pain	Good	Good	Much better	
5	Very effective	Very good	No problems	Prefer it to lumbosacral corset and spinal brace	
6	Not effective	Comfortable	Adequate	Does not give relief afforded by regular sacroiliac support issued at same time	

7	Not effective. Gives only minor support, does not relieve acute attack or prevent recurrence	Comfortable	Very easy to adjust	Prefer regular lumbosacral support which affords more relief and is more comfortable	
8	Good support for the back while working	Comfortable	Very satisfactory	More comfortable, can move about more freely	May not be as effective if he has a severe back strain
9	Not effective	Satisfactory	Satisfactory	Not as effective as a standard sacroiliac belt	
10	Hard to determine because of overall arthritic problem. Helps ease pain when lifting objects. Otherwise, about the same	Very comfortable (see column headed Other)	Very easy to adjust	No experience	Slips up and down if he doesn't get it tight enough. If tightened so doesn't slip, it gets uncomfortable. Patient wants to continue wearing it
11	Not effective	Comfortable	Good	More comfortable than other devices	Does not stay in place

cians commented that they saw very few cases during the course of a year requiring this type of support.

The following quotations are from the summaries completed by the participating medical staffs at the conclusion of the study.

"A pelvic belt of limited utility. I have seen very few indications for a belt of this type in my 17 years at the VA clinic. It is not intended (nor can it be used) for any sort of immobilization of the lumbosacral joint or any of the segments above it. The belt that was used was absolutely ineffective, although quite comfortable and adjustable. Its wear life was less than 6 months. It will probably not be often prescribed in this clinic."

"Of the three cases (#9, 10, 11), it seems highly questionable regarding the effectiveness with respect to therapeutic benefit. The simplicity and adjustability are appreciated by all, but very little relief has been obtained."

"From this limited study, the Cetrone Belt was not effective in relieving lumbosacral or sacroiliac pain or discomfort. In fact, it was reported to aggravate the symptoms, and it was uncomfortable to wear for over an hour or two."

"The adjustability of the belt is good, but in order for it to be effective, it must be drawn tight. This, in turn, binds the abdomen over a narrow area and is uncomfortable to the wearer."

"In my opinion, the belt is not indicated for these conditions since a lumbosacral corset gives more support and is much more comfortable to the patient."

Patient "experienced rather dramatic relief from his sciatica after fitting with a Cetrone Belt. . . . . however, he also experienced improvement of his low back pain while performing prescribed exercises and reducing his job demands. (#1) . . . . he (patient attributes this (relief) to his sacroiliac (Cetrone) belt."

"I think the feeling of well being is secondary to decreased lordosis resulting from use of the Cetrone Belt (#5)."

CONCLUSIONS AND RECOMMENDATIONS

Based on our rather limited evaluation of this device, due to the difficulty in finding patients for whom the device was felt to be indicated by prescribing physicians and the limited success where prescribed, we recommend that the device not be placed on contract. Although generally negative our findings were not conclusively so and we, therefore, propose the following:

Stations should be advised of the nature of the device and noncontract procurement be permitted with follow-up reports submitted to the Research and Development Division in order for us to gather further data. VA Prosthetics Center currently has on hand some 30 belts remaining from the study and these belts should be used for this purpose. These belts will probably be adequate for at least one year if our present experience is typical. It is not known at this time whether the developer will continue to produce these belts. In any event, we do not believe that there would be sufficient demand to justify stocking this item. Any savings in initial cost from quantity purchase of this low cost item would be offset by predicted long-term storage, handling, and shipping costs.

APPENDIX A

VETERANS ADMINISTRATION
Department of Medicine and Surgery
Prosthetic and Sensory Aids Service

Clinical Evaluation Study: Cetrone Belt

Medical Background

Date____________________

Patient______________________________ C#________________

Station ____

Age_______ Ht._______ Wt. _______ Occupation____________

Inpatient ☐ Outpatient ☐ Date of admission______________________

Diagnosis:

Is patient now in an acute stage?______________________________

When was last acute attack?______________ Duration______________

How many attacks has patient had in the last year?__________________

Last five years?____

If back support is worn routinely, describe support:

Does patient find back support effective? ☐ Yes ☐ No Explain:

Does patient consider the back support comfortable? ☐ Yes ☐ No Explain:

If patient is in an acute stage at this time, describe treatment program:

Does patient receive Physical Therapy when *not* in an acute stage? ☐ Yes ☐ No

If yes, describe program:

What size Cetrone Belt is desired? (adjustment range 6″–8″):

Hip size to 34″__________
Hip size to 40″__________
Hip size to 48″__________

____
Signature

____
Title

APPENDIX B

VETERANS ADMINISTRATION
Department of Medicine and Surgery
Prosthetic and Sensory Aids Service

Clinical Evaluation Study: Cetrone Belt

Follow-Up Report

Patient________________________________ Date____________________

Station ____

Inpatient ☐ Outpatient ☐ Date of admission____________________________

How long has patient been wearing a Cetrone Belt?____________________

Hours per day____________________Days per week_________________

What are the patient's reactions to the Cetrone Belt? (Consider relief from acute attacks and prevention of recurrences.)

A. Effectiveness:

B. Comfort:

C. Adjustability:

D. Comparison with other devices worn:

E. Other:

______________________________ ______________________________

Signature Title

APPENDIX C

VETERANS ADMINISTRATION
Department of Medicine and Surgery
Prosthetic and Sensory Aids Service

Clinical Evaluation Study: Cetrone Belt

Medical Staff Summary

What are your opinions regarding the prescription indications and contraindications for this device? Include comments on its effectiveness, comfort, adjustability, and durability. Any suggestions for improvement?

Signature—Title	Signature—Title
Signature—Title	Signature—Title

SURVEY OF UPPER- AND LOWER-EXTREMITY BRACE COMPONENTS

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Chief, Prosthetics-Orthotics Service
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INTRODUCTION

In an effort to improve orthopedic services for our disabled beneficiaries, a survey was conducted to determine the types of components VA Orthopedic Shops are using for the fabrication of upper- and lower-extremity orthotic devices. A questionnaire form was forwarded to 28 VA Orthopedic Shops requesting the following information: a. the numbers of each component used during fiscal year 1967 (July 1, 1966 through June 30, 1967), b. the costs of the prefabricated items, and c. the basic materials of each design used. Other information solicited was the use of custom fabricated items in lieu of prefabricated components and the reasons for their preference. Suggestions and comments as to future emphasis in research and development of orthotic devices were also encouraged.

Responses to the survey were quite informative. Almost all of the stations suggested that more emphasis should be devoted to research and development, especially in the field of upper-extremity orthotics. It was brought to our attention that the recently developed quadrilateral ischial weight-bearing socket and the patellar-tendon-bearing braces were developments that contributed substantially to solutions of lower-extremity orthotics problems. One respondent suggested that *adjustable* appliances be made available to determine the optimum function and fit of lower- and upper-extremity appliances. In principle almost all of the shops were in favor of utilizing standard, mass-produced prefabricated parts including those now making certain components because of physicians' preferences or because they are "set up" to custom make certain parts in fairly large quantities. The majority of the shops are utilizing noncorrosive, lightweight metals such as aluminum or stainless steel; in our opinion this is favorable. Hopefully carbon steel can be slowly phased out especially when one considers the availability of the special alloys of aluminum and stainless steel as well as the synthetics that are available. The data reveal another favorable trend in the purchasing of kits and assemblies rather than individual components. Purchasing in this manner will reduce costs and required stock levels and insure interchangeability of component parts.

RESULTS OF SURVEY

We encountered some difficulty in analyzing the data submitted in some cases because of the manner in which the shops purchase individual parts. A broad general breakdown of our findings by disability level is as follows (see Table 1.—*Results of Survey on Lower-Extremity Brace Components* and Table 2.—*Results of Survey on Upper-Extremity Brace Components*) :

TABLE 1.—*Results of Survey on Lower-Extremity Brace Components*

Item no.	Item	Annual use								
		Custom made			Prefabricated					Total prefabricated and custom made (prs./sets)
		None reported (shops)	No. used (shops)	Prs./sets	None reported (shops)	No. used (shops)	Prs./sets	Cost		
								High	Low	
	HIP JOINTS									
1	Hyperextension control	27	1	15 prs.	20	8	45 prs.	$15.70	$4.95	60 prs.
2	Hyperextension control w/ lateral motion	28	—	—	27	1	5 prs.	7.40	7.40	5 prs.
3	Drop-ring lock	27	1	2 prs.	16	12	61 prs.	14.85	7.70	63 prs.
	Total			17 prs.			111 prs.			128 prs.
	KNEE JOINTS									
4	Hyperextension control	22	6	56 prs.	14	14	105 prs.	$13.75	8.08	161 prs.
5	Drop-ring lock	25	3	41 prs.	7	21	476½ prs.	15.25	7.95	517½ prs.
6	Lever lock	23	5	10 prs.	14	14	102 prs.	20.75	12.25	112 prs.
7	Spring-loaded lever with spring adjustment	28	—	—	22	6	66 prs.	19.95	14.44	66 prs.
	Total			107 prs.			749½ prs.			856½ prs.

	ANKLE JOINTS									
8	Free motion or equino-calcaneus control	24	4	45 sets	6	22	227 sets	$10. 50	$4. 00	272 sets
9	Free motion or equino-calcaneus control w/detachable caliper	27	1	12 sets	15	13	235 sets	11. 43	2. 63	247 sets
10	Equinus control, spring loaded w/spring adjustment	27	1	20 sets	13	15	885 sets	9. 63	4. 70	905 sets
11	Equinus control, spring loaded w/spring adjustment w/detachable caliper	2	—	—	6	22	765½ sets	11. 64	4. 17	765½ sets
12	Equino-calcaneus control, spring actuated w/spring adjustment	28	—	—	18	10	51 sets	10. 82	8. 25	51 sets
	Total			77 sets			2163½ sets			2240½ sets
	JOINTS BELOW THE ANKLE									
13	Unlimited or free motion	27	1	6 sets	28	—	—	—	—	6 sets
14	Unlimited or free motion	21	7	56 sets	23	5	14 sets	2. 40	1. 18	70 sets
15	Equinus control	27	1	7 sets	28	—	—	—	—	7 sets
16	Equinus control spring-loaded, alloy (spring) steel	21	7	208 sets	19	9	57 sets	16. 35	2. 25	265 sets
	Total			227 sets			71 sets			348 sets

TABLE 1.—*Results of Survey on Lower-Extremity Brace Components*—Continued

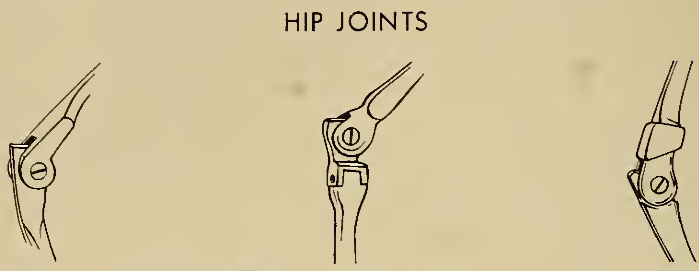
Item no.	Item	Annual use								
		Custom made			Prefabricated					Total prefabricated and custom made (prs./sets)
		None reported (shops)	No. used (shops)	Prs./sets	None reported (shops)	No. used (shops)	Prs./sets	Cost		
								High	Low	
	ARCH SUPPORTS									
17	Combination support, high flange (Schaeffer type)	19	9	367 prs.	17	11	252 prs.	$10. 78	$1. 75	619 prs.
18	Combination support, low flange (Schaeffer type)	21	7	398 prs.	22	6	56 prs.	10. 00	1. 95	454 prs.
19	Combination support with heel (Whitman type)	22	6	16 prs.	24	4	18 prs.	12. 50	6. 50	34 prs.
20	Combination support without heel (Whitman type)	28	—	—	27	1	2 prs.	12. 00	7. 50	2 prs.
21	Combination support (insole type)	20	8	239 prs.	18	10	407 prs.	9. 00	1. 95	646 prs.
22	Metatarsal support (insole type)	20	8	156 prs.	22	6	56 prs.	8. 00	1. 00	212 prs.
	Total			1176 prs.			791 prs.			1967 prs.

TABLE 2.—*Results of Survey-on Upper-Exremity Brace Components*

Item no.	Item	Annual use								Total prefabricated and custom made (each)
		Custom made			Prefabricated					
		None reported (shops)	No. used (shops)	Each	None reported (shops)	No. used (shops)	Each	Cost		
								High	Low	
	UPPER-EXTREMITY BRACES									
23	Finger extension splint (Bunnell)	21	7	60	24	4	36	$3. 50	$1. 00	96
24	Interphalangeal joint flexion brace (Bunnell)	24	4	15	21	7	45	4. 75	1. 75	60
25	Metacarpophalangeal joint flexion-extension brace (Bunnell)	19	9	51	19	9	102	8. 14	6. 50	153
26	Basic opponens splint (UCLA)	16	12	51	22	6	76	4. 00	1. 50	127
27	Wrist stabilization brace	12	16	254	24	4	25	13. 50	2. 90	279
28	Wrist extension assist brace (Oppenheimer)	18	10	56	20	8	75	30. 00	7. 00	131
29	Long opponens hand splint (UCLA)	19	9	101	19	9	147	5. 25	2. 00	248
	Total			588			506			

Hip Joints (Fig. 1)

Comparatively speaking, fewer hip joints are being used now as were several years ago. More than likely this is due to more frequent surgery, intensive physical therapy, and utilization of such lightweight leather and fabric hip control components as Silesian belts. Approximately 60 percent of the hip joints used were made of either stainless steel or aluminum and the ratio of prefabricated parts to custom-made parts was approximately 6 : 1.



HYPEREXTENSION CONTROL

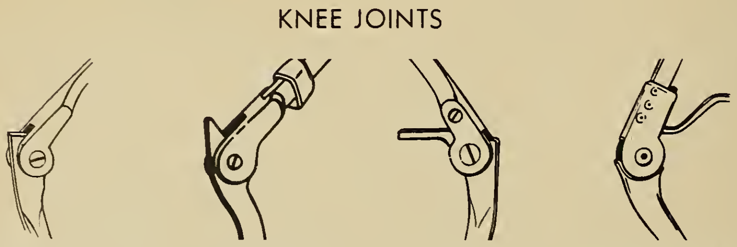
HYPEREXTENSION CONTROL WITH LATERAL MOTION

DROP-RING LOCK

Figure 1

Knee Joints (Fig. 2)

Approximately 60 percent of the prefabricated knee joints used by the Orthopedic Shops were made of either aluminum or stainless steel. Those braces that were fabricated of carbon steel were made especially for patients who would subject a brace to very rough use. The drop-ring lock brace joints were used most frequently; for every lever lock used, nearly three drop-ring lock knee joints were used. The ratio of prefabricated parts to custom-made parts was approximately 7: 1.



HYPEREXTENSION CONTROL

DROP-RING LOCK

LEVER LOCK

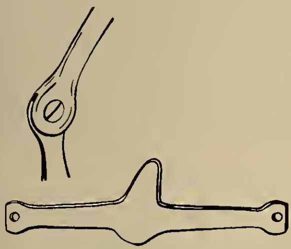
SPRING-LOADED LEVER WITH SPRING ADJUSTMENT

Figure 2

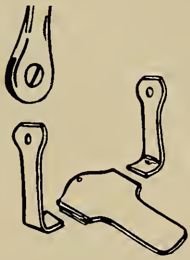
Ankle Joints (Fig. 3)

Most of the shops are purchasing these items in kits or sets with approximately 90 percent in stainless steel and/or aluminum; the remainder are heavy-duty carbon steel components. However, carbon steel, rectangular, detachable caliper plates were used in almost all instances for Items 9 and 11 (see Table 1) mainly because these items are not supplied in stainless steel by manufacturers. The ratio of prefabricated parts to custom-made parts was approximately 28:1.

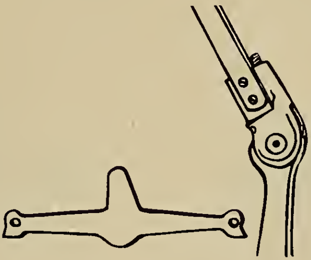
ANKLE JOINTS



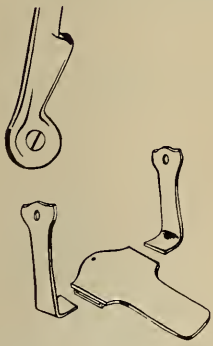
FREE MOTION OR EQUINO-CALCANEUS CONTROL



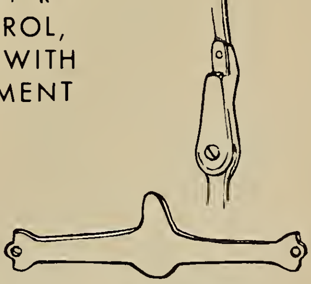
FREE MOTION OR EQUINO-CALCANEUS CONTROL WITH DETACHABLE CALIPER



EQUINUS CONTROL, SPRING LOADED WITH SPRING ADJUSTMENT



EQUINUS CONTROL, SPRING LOADED WITH SPRING ADJUSTMENT WITH DETACHABLE CALIPER



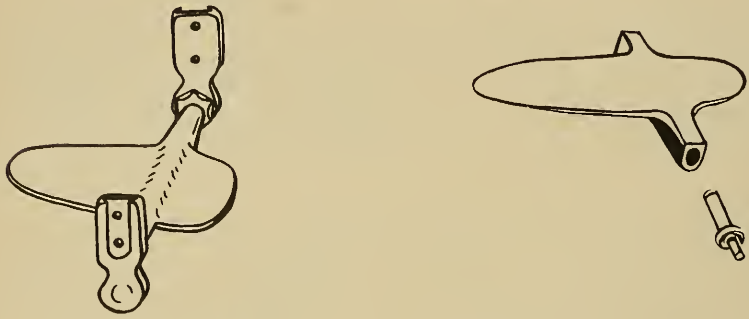
EQUINO-CALCANEUS CONTROL, SPRING ACTUATED WITH SPRING ADJUSTMENT

Figure 3

Joints Below the Ankle (Fig. 4)

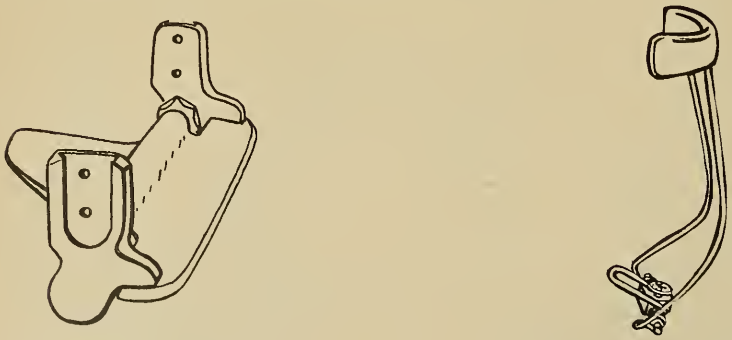
Very few caliper plates were used as compared to stirrups (Items 13, 14, and 15 in Table 1). Only 83 (both prefabricated and custom made) calipers were used during Fiscal Year 1967 and of that number 69 were custom made. This low number of 83 in our opinion is desirable. Except in rare cases, mechanical ankle joints should be located as close to the anatomical ankle axis as possible. The caliper plates were for the most part made of carbon steel. Most of the shops make Item 16 (Table 1) either of stainless steel wire or of carbon steel music wire. From the descriptions given, there is a great variance of design. Even among the manufacturers of these items the materials and appliances vary. The ratio of prefabricated appliances to custom-made appliances was 1 : 4. Without a doubt there is a need for standardization of design of this item.

JOINTS BELOW THE ANKLE



UNLIMITED OR FREE MOTION

UNLIMITED OR FREE MOTION



EQUINUS CONTROL

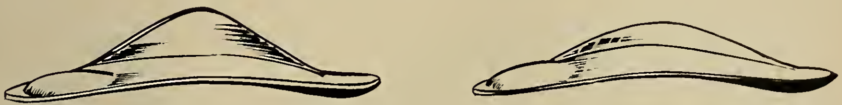
EQUINUS CONTROL SPRING-LOADED, ALLOY (SPRING) STEEL

FIGURE 4

Arch Supports (Fig. 5)

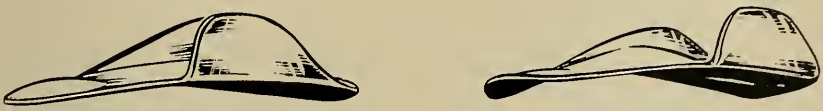
Approximately 75 percent of the prefabricated arch supports used were made of leather, fabric, and were with or without springs; the balance were made of stainless steel. Very few supports of the Whitman type (Items 19 and 20, Table 1) are being used. Except for Item 21 (Table 1, *Combination Support, Insole Type*) the greater portion of the other arch supports (Items 17, 18, and 22, Table 1) were custom made as opposed to purchased. However, we assume that many of the custom-made items are in reality purchased from manufacturers in a semi-finished state and then modified and finished by the shops. In our opinion the purchasing of semi-finished supports is a desirable method of providing arch supports. Because of the versatility in the design of such items, the orthotist can easily make minute changes, build-ups, or modifications. The ratio of prefabricated arch supports to custom-made arch supports was approximately 1 : 1.5.

ARCH SUPPORTS



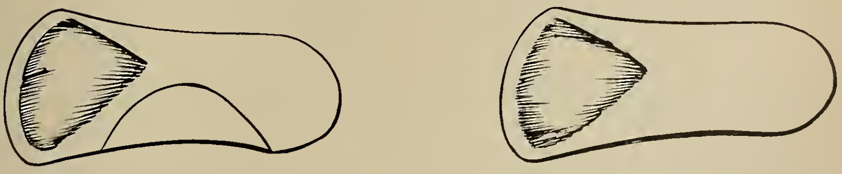
COMBINATION SUPPORT, HIGH FLANGE (SCHAEFFER TYPE)

COMBINATION SUPPORT, LOW FLANGE (SCHAEFFER TYPE)



COMBINATION SUPPORT, WITH HEEL (WHITMAN TYPE)

COMBINATION SUPPORT, WITHOUT HEEL (WHITMAN TYPE)



COMBINATION SUPPORT, (INSOLE TYPE)

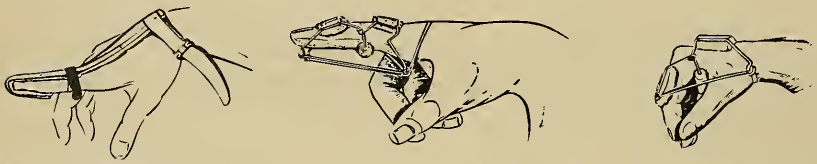
(METATARSAL SUPPORT (INSOLE TYPE)

Figure 5

Upper-Extremity Braces (Fig. 6)

Approximately 50 percent of the prefabricated appliances were made of aluminum, 45 percent were made of carbon and/or stainless steel spring wire, and 5 percent were made of plastic materials. The ratio of prefabricated items to custom-made items was approximately 1:1. We assume that many of the custom-made items were identical in design to items that are commercially available. The great variances in cost on several of the prefabricated items can be attributed to the manner in which the items were purchased: for example, Items 27 and 28 (Table 2) were purchased as entire kits, which included not only wrist components but also components that could be utilized for metacarpal, phalangeal, and thumb function. This naturally would bring the cost up considerably. In our opinion, more emphasis should be placed on the purchasing of the plastic and aluminum components now commercially available.

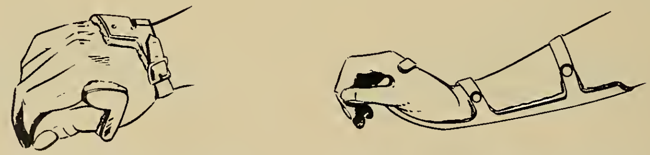
UPPER-EXTREMITY BRACES



FINGER EXTENSION SPLINT (BUNNELL)

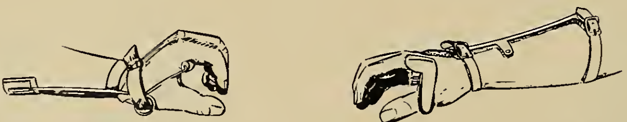
INTERPHALANGEAL JOINT FLEXION BRACE (BUNNELL)

METACARPO-PHALANGEAL JOINT FLEXION-EXTENSION BRACE (BUNNELL)



BASIC OPPONENS SPLINT (UCLA)

WRIST STABILIZATION BRACE



WRIST EXTENSION ASSIST BRACE (OPPENHEIMER)

LONG OPPENENS HAND SPLINT (UCLA)

Figure 6

DISCUSSION AND CONCLUSION

Generally, the custom forming of major lower-extremity components is on the wane; moreover, the upper-extremity picture is not totally unsatisfactory. There is also a noticeable reduction in the multitude of designs of both lower-extremity and upper-extremity prefabricated components. To a large extent standardization and uniformity do exist among prefabricated components used by the VA Orthopedic Shops. Therefore it should make our job much easier if a national brace contract is contemplated.

Almost 700 pairs of knee-lock joints of various designs were used for leg-thigh braces during Fiscal Year 1967. Undoubtedly some of these patients were, in fact, in need of joints of this type. But one wonders if many of the knee-lock braces, especially for the unilateral patient, could not have been of a more functional design. In our opinion there is a definite need for a lower-extremity *functional* knee lock to augment the armamentarium of lower-extremity orthotic components. We would recommend that an effort be made to stimulate a design and development project on a functional knee lock. We might establish functional specifications for such a knee lock and negotiate a contract with one of the manufacturers to develop such a device.

Several of the shops indicated that they do not use the detachable, prefabricated caliper stirrups because they develop play after short periods of wear, thus causing noise. We concur with this observation. We therefore suggest that the design of caliper stirrups be investigated to try to minimize the aforementioned shortcomings. Basically, the caliper stirrup idea is desirable because it makes the interchangeability of shoes much easier; costs are reduced in some cases since one pair of uprights can be used with several pairs of shoes. Furthermore, prefabricated caliper stirrups made of carbon steel are subject to early corrosion since they are attached to the bottom of the shoe and are therefore close to the ground. We suggest that stainless steel, even though slightly higher in cost, be considered for detachable caliper stirrups.

There are several designs of the equinus control wire drop-foot brace (Item 16, Table 1) commercially available. This item in our opinion should be of one standardized design. We might eventually consider the "pre-preg" epoxy-Fiberglas material that we are evaluating for AMBRL or the "pre-preg" materials made by a fishing rod manufacturer, DePew Company, Hicksville, Long Island, New York.

The concept of using adjustable appliances is a good one. In fact, we have a design for leg braces that could easily be modified by a clinic team and thus used as a diagnostic tool for determining the function most suitable for a given disability. Moreover, a related suggestion was made by A. Bennett Wilson of the National Academy of Sciences several years ago. But, his suggestion as we recall had to do with permanent-type leg braces having a series of adjustable features that would be "locked" into position.

The preponderance of arch supports used are of the non-rigid, leather, fabric, and/or spring type as opposed to metal arch supports. In our opinion, the non-rigid flexible support is superior to the rigid metal support inasmuch as the former provides a certain amount of dynamic function. The non-rigid type may be purchased completely finished or semi-finished and it would be desirable for the Orthopedic Brace Shops to stock both types of supports but utilize more of the semi-finished supports for the severely disabled foot.

Approximately 45 percent of the upper-extremity braces were custom made and from the descriptions given in our survey, many of these items are identical to appliances that can be purchased at minimum cost from manufacturers of prefabricated upper-extremity appliances. We also recommend that many of the appliances be purchased as complete items or in kits, *for specific disability levels,* thereby reducing costs.

Several of the VA Orthopedic Shops intimated that orthotic components should be considered for centralized distribution; four Shops made positive statements to this effect. We certainly agree with the Orthopedic Shops' recommendations that there is a need for more research and development in the orthotic field; many of the Orthopedic Shops volunteered to participate in such research and development. In the meantime, VA Orthopedic Shops should be made aware either by Newsletter or other media of those developments that have proven their worth by satisfactory clinical experience.

A REVIEW OF THE VETERANS ADMINISTRATION BLIND GUIDANCE DEVICE PROJECT

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INTRODUCTION

Despite the excellence both of the long cane and of the dog, when used by trained people, relatively small fractions of the totally blind population use either. While these proportions are likely to increase with the current development of rehabilitation centers specializing in mobility training, there appears also to be some demand for a device which would not interfere with other pedestrians by physical contact, would be relatively inconspicuous [a] and would permit operation in crowded and noisy environments where auditory cues are absent or useless.

Any mechanical method for detecting hazards during travel by the blind should fulfill at least three functions:

1. It should detect obstacles and roughly indicate their proximity. Large obstacles such as walls are rather easily detectable by auditory cueing, if the blind traveler is experienced and has good hearing. However, obstacles such as chairs, posts, awnings, lamp posts, fire hydrants, projecting mail boxes, trash cans, mesh trash receptacles, projecting doorsteps, and doors standing ajar cause considerable discomfiture to the unaided blind traveler. A special difficulty posed in traveling over familiar ground is the appearance of unexpected obstacles such as movable trash cans, children's toys, or pedestrians.

2. It should detect down-steps and holes. These may take the form of downward curbs, down-going flights of stairs, edges of train platforms, docks, open manholes, and cellarways. A relatively unexpected hole, such as an open manhole, usually has some form of guard for the protection of sighted careless perestrians. On the other hand, a down-curb, a flight of stairs, or a sudden increase in the steepness of a hill poses special problems.

3. It should detect up-steps and low obstacles as exemplified by upward curbs, low steps, and similar stumbling blocks which may well be too small to be detected by other methods used primarily for detecting walls and doors.

---

[a] Some blind persons prefer an indicator of blindness comparable to the white cane or the dog as a warning to motorists.

Some blind individuals would also like a travel aid to help them walk in a straight line and to give compass bearings. A magnetic compass has been adapted to this purpose by Jacobson (1), while Swail has used the directional attributes of a radio antenna to make a direction and straight line sensing device. Though these devices function satisfactorily, they seem to be too cumbersome for the amount of information that they supply, so that they have not become popular.

From a mechanical point of view the instrument should be small, light in weight, easily stored when not in use, and easily picked up and put down. An instrument for the use of which someone must get "dressed up," with wires running through shirt sleeves and lenses mounted on a hat or the toe of a shoe, is so cumbersome that few blind people would consider the aid to be worth the trouble. Furthermore, it should be quiet in operation and not present any signal to the user except when encountering an obstacle. The signal that is then presented to the user should, if possible, be tactile rather than audible, because the blind traveler would like to reserve his ears for naturally occurring auditory cues.

This paper will review the numerous principles and devices suggested to meet these requirements, trace the history of our project, and describe the Bionic C4 Laser Cane currently being built for clinical application studies under the auspices of the Veterans Administration.

DEVICES SUGGESTED AND TRIED

Altogether about 25 guidance devices working on a variety of principles have been built by many investigators under various sponsorships in the last 20 years. The devices and the thinking behind their development are described in varying details in the publications listed in the bibliography. Broadest coverage can be found in "Blindness" (2) and, more recently, in "Proceedings of the International Congress on Technology and Blindness" (3), while others (4, 5) contain quite comprehensive bibliographies.

A few devices have operated from ambient light reflected by the obstacle, but most have radiated a beam of sound or electromagnetic radiation and detected the reflected ray. In most cases range information is elicited as well as information regarding the presence or absence of the obstacle.

Historically, most investigators have considered the detection of substantial obstacles, such as walls or doors, as their principal goal. Gradually, with increasing study of the problem, they have realized the importance of step-down detection also, obviously considerably more difficult than the detection of large conventional obstacles. In addition, they have recognized the less serious step-up detection problem, which, while superficially related to the obstacle detection problem, is, indeed, of a further order of difficulty.

Most recently, the problem of head height obstacles has also been considered.

Most devices have been designed simply to alert the user to the presence or absence of an obstacle, though some also attempt to give information regarding the texture of the objects sensed. Of course, the more information that is displayed, the more user training is required.

Throughout the development of these devices, the greatest emphasis has been upon systems by which an otherwise able-bodied individual, lacking only vision, could find his way about safely at a reasonable walking speed of 3 or 4 miles per hour. The individual's reaction time, stumble recovery, and general physical condition are expected to be normal or perhaps even somewhat above average.

Sonic Devices

Reflection of sound forms the most versatile source of travel information available to the blind. Supplementing other ambient sound, sound from the tap of a cane or the scuff of a foot reflected from an obstacle, will announce its presence to the acutely perceptive blind person. But the newly blind traveler, or the experienced man in a noisy street will find these echoes too faint. To overcome these problems several workers have developed small, easily carried horns that generate high frequency sound in sharp bursts to augment the more naturally occurring but less intense sound usually employed. Twersky (6) and Witcher (7) each produced useful instruments of this type. At first glance this might seem to be a very desirable system, since it employs the natural faculties of the user to a maximum. However, this is not a satisfactory solution, as it is not possible to obtain a sufficiently narrow beam for frequencies in the audible range. The highest frequency that seems practical is 10 kHz. If it were to be higher than that, too many people would not be able to hear the reflections. At 10 kHz the beam width is so wide that too much reflection from the ground confuses the pattern. It works under ideal conditions, but not under actual operating conditions. It also makes enough noise to be an "attention getter." However, it is probably a useful teaching aid.

Ultrasonic Devices

Until a few years ago, ultrasonics did not seem to be a very promising approach. There are several factors against its use and only one in its favor. On the positive side, the speed of transmission of ultrasonic waves makes it possible to employ time of flight (sonar) ranging principles. This is not yet practicable with electromagnetic waves, since the distances are short and the speed of transmission is quite high. About 25 years ago the Hoover Company and the Brush Development Company each built an ultrasonic device, while Stromberg Carlson tried several ultrasonic systems employing simple time lapse, single and multiple echo, and frequency modulation (8, 9). None of these proved to be satisfactory. Thermal and convection currents in the air introduced refraction effects that quite frequently completely obliterated signals. One blind evaluator (T. A. Benham) vividly recalls standing still while observing a tree trunk about 10 ft. away and noticing that the tree would seem to come and go in a most disconcerting manner.

More recently, Leslie Kay has tried again and produced a successful instrument (10). Using wide-band transducers, the instrument transmits a signal whose frequency varies with time between 30 kHz and 60 kHz. The signal returned from an object is mixed with the then outgoing signal to produce an audio beatnote whose pitch varies with range. If the surface of the object is rough or intermittent, like the foliage of trees or stalks of grass in a lawn, the signal will have several frequency components, giving it a "rough" sound as compared to the much purer tone generated by a smooth wall. Furthermore, the loudness will depend on the sound reflectivity or "hardness" of the surface. Thus, the instrument will give a rich information return. The device has been evaluated and reported on in this country (11, 12) [b] and is currently undergoing further evaluation in England and in Sweden.

Lindsay Russell of MIT has also developed an ultrasonic device which is worn on the chest, with a strap around the neck. A small earpiece warns of an obstacle in the path. This device is much easier to learn to use than the Kay device and it is less encumbering; but, of course, it does not produce as much information.

UHF Devices

Another possible approach which is frequently suggested is the use of radar. In general, a true radar system would presently be too heavy for portable use and unsuited to the very short ranges involved in a practical device for the blind. However, one system that has been suggested comprises a 1/4 wave antenna which changes the frequency of a high frequency oscillator when it nears an obstacle. This is the principle used in the proximity fuse.

Recently, with the advent of the Gunn Effect diode oscillator, a miniature laser-type guidance radar has been attempted. However, it does not measure range, but speed of approach (13).

In another approach, the Franklin Institute, on a grant from the Kellogg Foundation, developed a cane (14) using UHF which senses capacitively the distance between the tip of the cane and the ground or other obstacles. With this device the user has essentially the protection of a normal, reasonably long cane, but usually does not have to touch the ground physically. He is able to carry the tip of the cane a few inches off the ground without receiving any tactile or audible signal. If the tip then passes over the edge of a down-curb, the distance to the ground suddenly increases, the capacitance between the end of the cane and the ground changes abruptly, and a signal is given. This approach has the disadvantage that the detection range is limited to only a few inches more than the length of the cane; thus it cannot provide early warning.

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[b] Another evaluation, "Short Term Field Evaluation of Type 8A9 Ultrasonic Aid for the Blind," appears elsewhere in this issue.

A similar type of electronic cane was later developed by August W. McCollum of SITE Inc. (Sight Implementation Through Electronics).

Passive Systems Using Light

It is possible to build a system that detects an object by means of reflected ambient light. Such a "passive" system has the advantage of saving the power, weight, and space required by an "active" system that carries its own light source. One extremely ingenious and well engineered instrument was called "Optar" (15). This device detected ambient light reflected from the obstacle and determined the range by automatically measuring the image distance, the distance behind a lens at which an obstacle would be in sharp focus. Information was presented as a tone, the pitch of which indicated distance. In practice the tone was complex and difficult to interpret, and the device in the form in which it was constructed was not capable of detecting down-curbs.

Our laboratory studied the possibility of finding objects by detecting the contrast between adjacent areas of differing reflectivity. The system required too much ambient light to be practical for any but specially selected objects. Ranging was to be accomplished by finding the image distance, as in the Optar system described above.

Active Systems Using Light

A device working in the same part of the spectrum but carrying its own light source was developed by Dr. Lawrence Cranberg, then of the Signal Corps (16). RCA later manufactured 25 experimental units. Figure 1 shows the model of this device manufactured by RCA.

Briefly, the principle of operation is as follows: A beam of light interrupted 500 times per second emanates in a narrow beam from an optical system, strikes an object or the ground, and is diffusely reflected back into the second optical system. This second optical system focuses the image of the spot of light reflected from the object on a coding disk, behind which is located a photoelectric cell. The output of the photoelectric cell is fed through an electronic amplifier tuned to 500 Hz to a vibrator in the handle of the instrument. The coding disk interrupts the reflected light 4, 8, 16, or 32 times per second, depending upon the distance to the object. Thus the rate at which the 500 Hz pulses in the handle are modulated by this lower frequency informs the user as to the distance to an obstacle, while the position of the handle indicates the azimuth: that is, whether the obstacle is to the left, to the right, or straight ahead. Tuning the amplifier to 500 Hz gives the

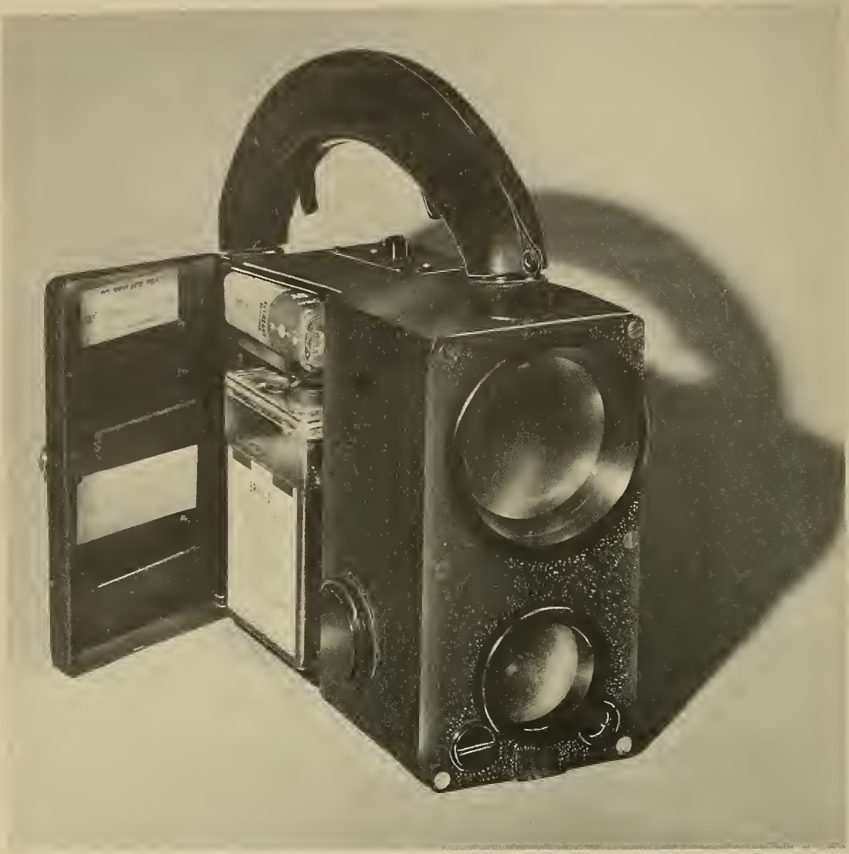


FIGURE 1.—Signal Corps Obstacle Detector manufactured by RCA.

system a favorable signal-to-noise ratio and helps discriminate against ambient light and low frequency transients.

Another recent RCA device (17), built on the same basic principle of optical triangulation, makes use of their recently developed room temperature solid state laser. The device is somewhat cane-like. It sends out two beams of light at different angles which return reflections from the ground at approximately 3 ft. and 6 ft. in front of the device. Interruption of a beam is signaled by interruption of the appropriate finger stimulator pulses. If both stimulators go dead, the ground has disappeared altogether, while interruption of one stimulator indicates a curb or step. The present device is a study model, and it is not presently known if RCA is planning further work.

Another optical triangulating device using visible light was built by the late Dr. Clifford M. Witcher at the Massachusetts Institute of Technology. He gave considerable time and thought to the overall problem of obstacle detection; to the special aspects of auditory localization, including the presentation of information in a map-like display (extending the work of Sokal (18)); and to the detection of step-downs or curbs. For this last problem he developed a test model of a device intended to be fitted in a briefcase, which projected a beam of light obliquely forward and downward upon the ground and then scanned this beam back and forth along the ground, nearer to and farther from the user. The beam was projected through the lower of two lenses, while a photocell was placed behind the upper lens. So long as the spot was on level or uniformly sloping ground, the optical system received a solid uninterrupted spot of light. If, however, the beam of light projected over the edge of a curb, there was a momentary interruption in the spot because the curb cast a shadow. While there seemed to be some difficulty in keeping the optical systems in focus over the rather wide range of distance involved, a ratio of about two to one, this difficulty could probably have been overcome by adding an automatic focusing arrangement coordinated with the scanning of the spot back and forth. Dr. Witcher's untimely death prevented further development of this concept.

Ultraviolet Device

Under the Committee on Sensory Devices, the Franklin Institute Laboratories for Research and Development worked on an optical triangulation ranging system using ultraviolet light. Ultimately the basic idea was given up because it was not as realizable as the Signal Corps device, also employing the principle of optical triangulation.

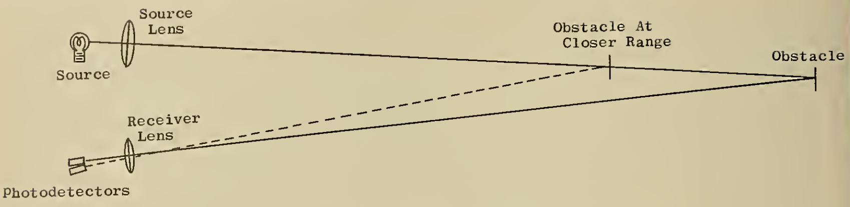
BIONIC INSTRUMENTS, INC.: EARLY DEVICES

The RCA version of the Signal Corps device described above was evaluated by Professor Benham in 1950, and his evaluation report (19) contained a list of recommendations which became the specifications for the series of instruments developed by our laboratory.

In 1953 the Veterans Administration contracted with Haverford College to develop, under the direction of Professor T. A. Benham, an improved version of the Signal Corps device embodying, wherever that might be practical, the desired features enumerated in the Haverford Evaluation Report. Haverford College subcontracted the laboratory development to Biophysical Instruments, Inc. (now Bionic Instruments, Inc.), leaving the evaluation to be performed by Haverford directly. The rest of this paper reports the thinking, design philosophy, and hardware that have flowed from this assignment.

Ranging by Triangulation

The optical principle of range determination by triangulation used in the guidance device may be explained by reference to Figure 2. A beam of light sent out by a source lamp is focused by the source lens on an obstacle which



Triangulation principle used in obstacle detectors. A light source is focused by a source lens on an obstacle. Two obstacles are shown at different ranges. Some rays from the image of the source appearing on the obstacle are focused by the receiving lens onto a photosensitive receiver. Obstacles at different distances reflect light to different receivers to discriminate range.

FIGURE 2.—Triangulation principle used in Signal Corps and Bionic guidance devices.

may be at any distance within the range of the obstacle detector. Two arbitrary positions for the obstacle are shown. Specular or mirror-type reflections from these obstacles generally will not return light to the receiving lens, because the angle of return of the reflected ray will depend on the angle that the reflecting surface of the obstacle makes with the central source ray. However, unless the obstacle has a very shiny surface, a small amount of light will be reflected from it in all directions (diffuse reflection). Regardless of the position or the angulation of the obstacle, there will thus exist a pencil of rays that will run through the center of the receiver lens to form an image as shown in the figure. Thus the location of the image with respect to the lens axis will be a measure of the distance to the obstacle. Note that in this system range determination is independent of the optical characteristics of the obstacle so long as enough light can be diffusely reflected to be electrically detectable. Most vertical objects, even black objects, will diffusely reflect enough light to be detected. However, mirrors, clear glass, and oblique or horizontal surfaces that are very dark or very shiny will cause trouble.

The obstacle detector is only required to discriminate range crudely. In fact, the first two models were built with no ranging discrimination at all. However, limited field tests with these models indicated that some range discrimination was desirable.

Early Models

At the beginning of the project the problem of curb detection was separated from that of obstacle detection, because the former was more difficult than the latter, and we couldn't even do the latter! Several generations of obstacle detectors were developed, culminating in the three range detector, Model G5 (3), shown in Figure 3 and the much smaller nonranging "flashlight" shown in Figure 4.

The G5 had a short range of 5 ft., a medium range of 10 ft., and a far range of 35 ft. An obstacle was signaled tactually by a stimulator in the

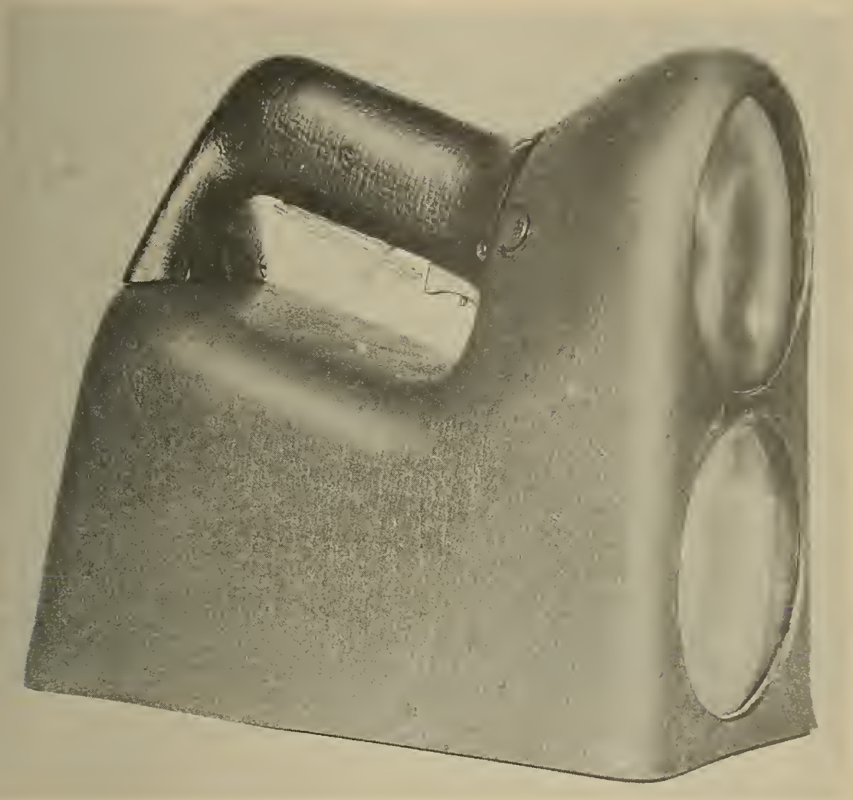


FIGURE 3.—Bionic G5 Obstacle Detector.

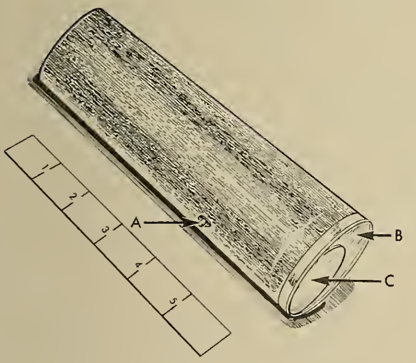


FIGURE 4.—Bionic Nonranging "Flashlight" Obstacle Detector: A. tactile stimulator, B. receive lens, and C. transmit lens.

handle. The instrument was rather inconspicuous and quite rugged. It weighed about 2 lb., complete with rechargeable batteries.

Approximately 15 units were built and evaluated for use on level ground by Tracor (20) in 1965. Tracor trained a group of blind travelers in "mazes," on a street, and in a store. It was concluded that the instrument increased the speed of the otherwise unaided traveler and that the users made about the same number of errors as with conventional devices. However, it actually slowed down the cane or dog user. It seemed that the user, upon encountering an obstacle, would frequently stop to explore in more detail, thus slowing down his travel but increasing his knowledge of his environment. Whether this kind of performance is considered "good" or "bad" depends on the desires of the user.[c] Further, it was determined that the absence of hole detection was quite a serious lack, though the device had been designed only for obstacle detection. It was so serious, in fact, that most travelers felt quite insecure unless they could also carry a cane in their other hand to probe for stepdowns. A few devices were fitted with downward probing automobile antennas, but the antennas were unacceptably flexible. Under these conditions, the device became an added encumbrance that was more trouble than it was worth.

These tests clearly showed, then, that it would be highly desirable to incorporate the guidance device into the body of a cane so that the user would have only one device to carry, and further, that it was quite important to incorporate a stepdown detector if at all possible.

Fortunately, at just about this time solid state infrared generators began to be developed. As with many of our previous instruments, the first one was built around a component that was not yet commercially available. It took the form of the nonranging "flashlight" shown in Figure 4. By the time the rest of it was finished the light generator it needed was on the market. Though it was small and light in weight, this "flashlight" had a maximum range of only 6 ft.; so it was useful primarily as a study model.

We next attempted a three channel cane. This cane (see Fig. 5), like the "flashlight" that preceded it, demonstrated that technology now made possible the compression of many components into what had been considered heretofore an unrealistically small space. The use of integrated circuits, small Fresnel lenses, and a solid state (gallium arsenide) light source made that compression possible.

The cane incorporated three complete detectors. In addition to a detector that looked straight ahead, an upward looking one provided coverage of the head and shoulder region, while a downward looking one gave warning of large dropoffs. Like its predecessor, the "flashlight," it was quite insensitive because of the low output of the light source. Furthermore, its human

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[c] Later trials showed that when subjects were encouraged to speed up and use the device only to look for a clear path they were able to do so.

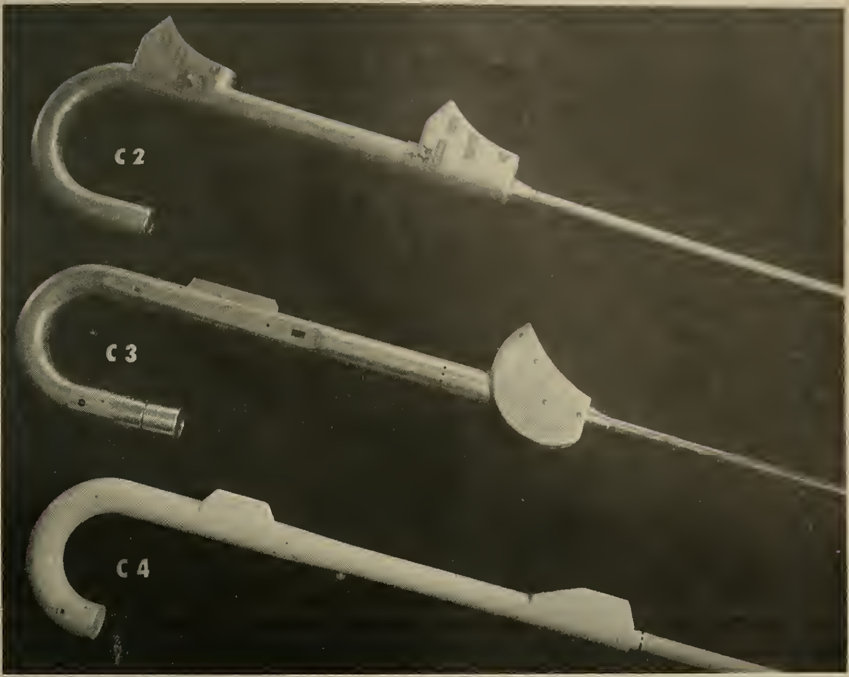

Figure 5.—C2, C3, and C4 Bionic Canes.

engineering was quite poor because major emphasis had been on technology. The weight and balance were bad, switches were located in unmanageable places, and the tactile output signals were almost unusable. However, it did allow a test of the idea of a beam to protect the upper body, heretofore untried.

Just about the time that this cane was completed, technology took another leap forward. There became available a light source made of the same gallium arsenide, but so doped and fabricated that it was a true laser at room temperature. Now, with almost 1,000 times more light available, it was finally possible to build a cane that would have the power required to work at realistically useful distances.[d] Furthermore, with the batteries made lighter, it became reasonable to look into a wide variety of materials in order to make the rest of the cane lighter.

So, in 1966, the first true laser cane built by us was completed (21). It is also shown in Figure 5. It was informally evaluated by over 50 blind travelers and trainers of the blind, and as a result of that evaluation the present model, the C4, was developed. It is shown in use in Figure 6 and next to the C2 and C3 models in Figure 5.

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[d] The laser used in this application has at least 100 times less power than would be required to cause eye damage if the laser light were focused directly on the retina.

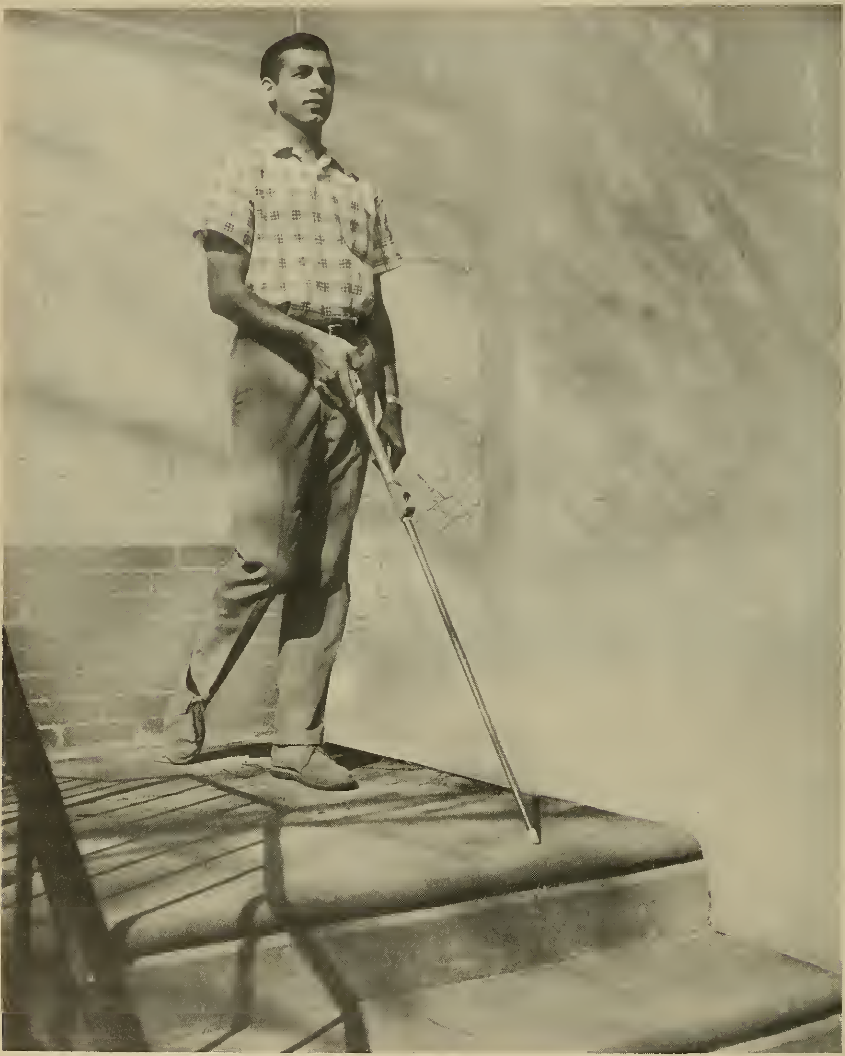

FIGURE 6.—C4 Laser Cane in use.

THE BIONIC C4 CANE

General Description

The functioning of the cane can be understood by reference to Figure 7. The end of the crook contains a sound generator used for warning of dropoffs and overhangs. The curved portion of the crook houses the electronics to drive the sound generator and the batteries that power the whole system. Proceeding down the front of the cane, at the top is the circuitry that drives the three lasers that generate the three separate light probes

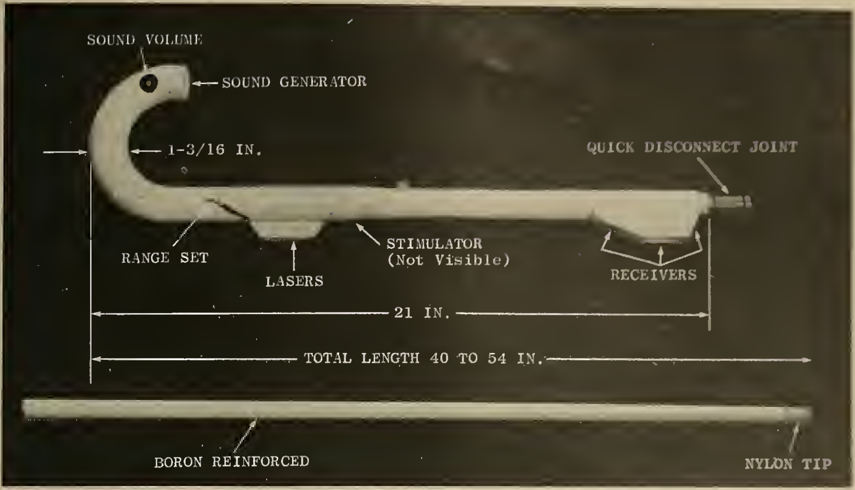

FIGURE 7.—Close-up of C4 Laser Cane.

which look down, ahead, and up. Next come the lasers themselves, situated behind the lens system. This assembly forms the upper nacelle. Above this nacelle is a small lever that can be moved to adjust the maximum range of the straight ahead channel. The housing is broken again 9 in. below the bottom of the upper nacelle by the start of the larger lower nacelle, which houses the receiving optics. The space within the cane between these two optical housings is occupied by receiving and logic electronics as well as a poking-type stimulator. This stimulator is situated on the right side of the cane shaft between the two nacelles in a position to contact the ball of the index finger when the cane is being carried in the right hand as a "long cane." It signals the detection of an object in the field of the straight ahead channel.

The strength of this stimulus has been made independent of the strength of the light reflection from the object, since such information was considered to be more confusing than helpful.

The other two channels, however, were arranged to give an auditory output for several reasons. One stimulator could conceivably be used with three coded stimulator pulse patterns, but the time required to interpret such coded bursts was considered to be too long. Three separate stimulators could be used, but besides taking additional space and power, this solution would require a more rigid hand posture that was judged to be too tiring. Finally, it was postulated, and later confirmed, that brief auditory tones would be better "attention getters" than a tactile stimulus. This would seem desirable for the dropoff and overhang channels, whose warning of difficulties really ought to be strident.

Since these two channels emit signals only occasionally, it was considered that the auditory signal would not be objectionable. The upward looking channel has been set to emit a high pitched tone (about 2200 Hz); the downward looking channel emits a lower pitch (1200 Hz); while if the two channels go off simultaneously, an intermediate tone is produced. The sound generator is a piezoelectric crystal mounted in the end of the crook. A control allows the user to adjust the volume so as to produce a signal loud enough to overcome ambient noise without attracting undue attention.

Stimulator

It was decided that the best way to signal the presence of an obstacle to the user was through a tactile stimulator in the handle of the obstacle detector. This mode of communication lends itself to keeping the device simple to use and avoids the necessity of using the complicated harnesses required by electrical or aural stimulation. Aural stimulation for the most frequent signals was ruled out from the very start, because of the desirability of keeping the ears free for normal cues.

To minimize the size and weight of an obstacle detector, considerable design effort has been directed toward minimizing power requirements. Accordingly, an experiment was performed to determine how much power was needed to alert the user reliably. Two modes of tactile stimulator were thought to be possible:

1. A poking stimulus such as would be provided by a small blunt pin activated by a solenoid.
2. A rubbing or scratching stimulus such as that produced by moving a rough surface across a fingertip.

The latter might be more desirable because it would activate more nerve endings and might reduce the tendency to fatigue.

In order to test these two stimuli and to determine the amount of power they required, a special piece of apparatus was built. The device for providing a rubbing stimulus is shown in Figure 8. It consists of a shaft mounted in very low friction bearings and two disks mounted on that shaft. D_1 is a disk against which the shaft of a motor may be touched in order to bring the rotating system up to some predetermined angular speed. D_2 is a large disk on which is located a rough stimulating surface. The finger gains access to this stimulator through a guard in which are drilled "finger" holes. As the disk rotates, the rough surface rubs the finger tip once each revolution. The percentage of the time that the stimulus is presented to the finger during each revolution can be varied from 5 percent to 50 percent by changing the length of the rough surface glued to the side of the disk.

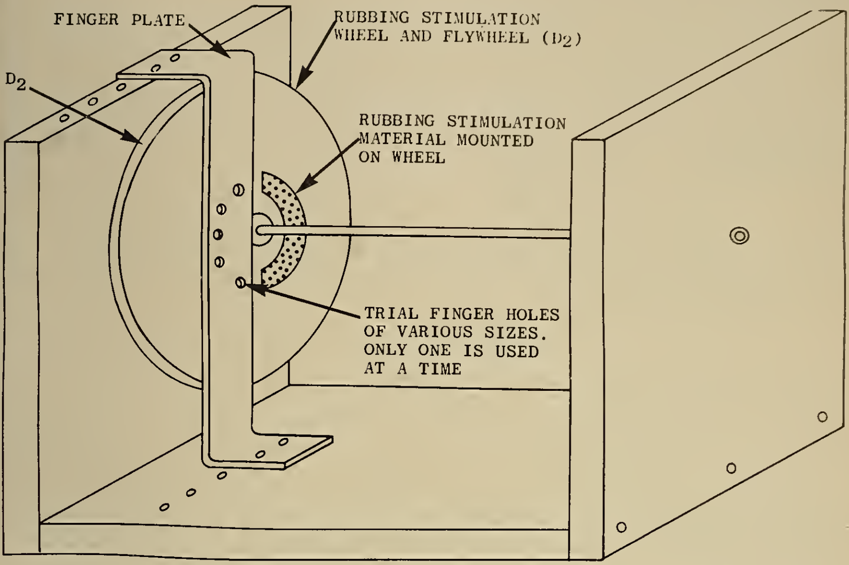
FINGER PLATE
RUBBING STIMULATION WHEEL AND FLYWHEEL (D2)
D2
RUBBING STIMULATION MATERIAL MOUNTED ON WHEEL
TRIAL FINGER HOLES OF VARIOUS SIZES. ONLY ONE IS USED AT A TIME

Figure 8.—Experimental device for measuring rubbing stimulus power requirements.

Tests with the rubbing stimulus showed that the fingertip fatigued after the first two or three seconds. In the case where 50 percent of the disk was covered with stimulating surface, the power required was about 75 milliwatts.

In an effort to learn what would be required for a poking stimulus, the apparatus was altered as shown in Figure 9. A cam was fitted to a shaft arranged to raise and lower a spring-loaded pin. This pin protruded about 1/32 in. above the finger plate at the top of the stroke and was about the same distance below the surface of the plate at the bottom of the stroke. The results indicated clearly that the power required for this type of stimulus was about the same as for the rubbing stimulator. The poking stimulator had the advantage, however, that the finger could be more readily moved slightly from time to time to expose a fresh set of nerve endings to the stimulator. In this way the effects of fatigue could be reduced. Also, from the engineer's point of view it seemed easier to make a poking device than a rubbing device; consequently, it was decided to use a poking stimulator.

The design uses an Alnico magnet approximately half the length of the coil as the moving core of a solenoid. The stationary field of the solenoid is wound with two adjacent coils connected in series opposing so that their poles point the same way with respect to the magnet armature. This arrangement gives maximum force in a limited space. The direction of the electromagnetically powered armature motion is away from the finger to be

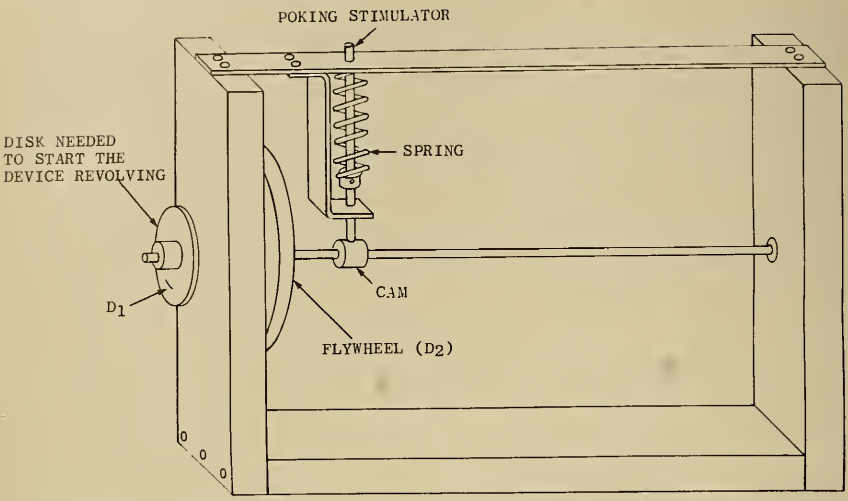

Figure 9.—Experimental device for measuring poking stimulus power requirements.

stimulated. In so moving, the armature compresses a spring, which then propels the armature toward the finger when the coil current stops. On the side of the armature toward the finger is glued a small length of piano wire to act as a stimulating element. This wire protrudes through a hole in the side of the cane against which the finger is pressed. The hole is made small enough to keep the finger from touching the wire stimulating element when the armature assembly is at rest. This arrangement allows for maximum energy transfer to the finger and, at the same time, allows for variations in finger pressure against the sensing hole.

Optics

The basic optical principle of range detection, "Optical Triangulation," is described earlier. The sensitivity of such a system to a range change is directly proportional to the distance separating the lenses. Thus the configuration used in the cane is excellent for this ranging system, since it allows several inches of separation between the source lasers mounted in the upper nacelle and the receiver photocells mounted in the lower nacelle. The separation in the present cane is about 9 in. The cane is normally expected to be held in the position of a conventional long cane, about 45 deg., and the optics are set accordingly.

The "straight ahead" optical train consists of the lowest source (upper nacelle) and the center receiving lens (lower nacelle). Maximum range for the system is set by adjusting the angle of the source lens-laser assembly, which is mounted in the nacelle on a pivot so that it may be rotated by sliding the range adjusting lever referred to in the general description and shown in Figure 7. Pushing the lever forward extends the range. The most forward position corresponds to 12 ft. from the cane tip. The system is capable of sensing up to 18 ft., but most travelers do not find it desirable to observe more than 12 ft. ahead. Pulling the lever back moves the range in; the minimum distance possible is the end of the cane itself. This arrangement allows the traveler to walk in a congested area without receiving more signals than he feels is necessary.

The image formed by the receiver lens will move as the range changes, so the photodiode that responds to this image must be a rectangle with a width equal to the long dimension of the light source and a length equal to the travel of the image as the detected object moves from the cane tip out to the maximum distance set by the laser lens angle.

The laser light is a rectangle approximately 400 microns by 30 microns. Thus, even at 10 feet, when imaged through a lens with a focal length of 13 millimeters, it has only spread to a beam approximately ¾ in. wide and would make an image that long on a receiver diode placed at that point. For this reason it is possible to gage rather accurately the width of an obstacle by a slight rotation of the cane. Figure 10 shows the beam coverages.

This figure also shows the beam coverages for the upward and downward looking beams, neither of which is movable by the user, though they are both adjustable internally to fit the height and stride of the individual user.

The upward going light train is formed by the uppermost source lens and the uppermost receiving lens. It must be the most accurate ranging system of the three because it must protect the head without giving a false alarm for a door jam that may be only 6 in. above the head of the user. It is also adjusted to sense only out to a point perpendicularly above the tip. Earlier experiments showed that sensing beyond this point caused confusion and was unnecessary. If the user is warned of an obstacle at head height just before he is about to hit it, he can easily stop and reach up and out to verify that warning.

The downward looking channel contacts the ground approximately 3 ft. in front of the cane tip, 5½ ft. from the forward foot, in order to provide two steps of warning. So long as any light is returned from the ground, the device is silent. It gives a signal to the user only if the light disappears. An abrupt dropoff of about 7 in. is required, so that the device will not reliably detect small down-curbs or small single steps. There is another mode of operation, however, by which it may be made more sensitive. Frequently there is a change in the color of the terrain between the sidewalk and the street. Usually the street is darker. In such cases the sensitivity of the receiving amplifier may be reduced so that the signal returned from the darker surface of the street, taken in combination with some optical signal loss due to the down-curb itself, will be enough to register as "no return." The present cane contains a gain control that is user adjustable to see if this feature is sufficiently useful to be worthwhile.

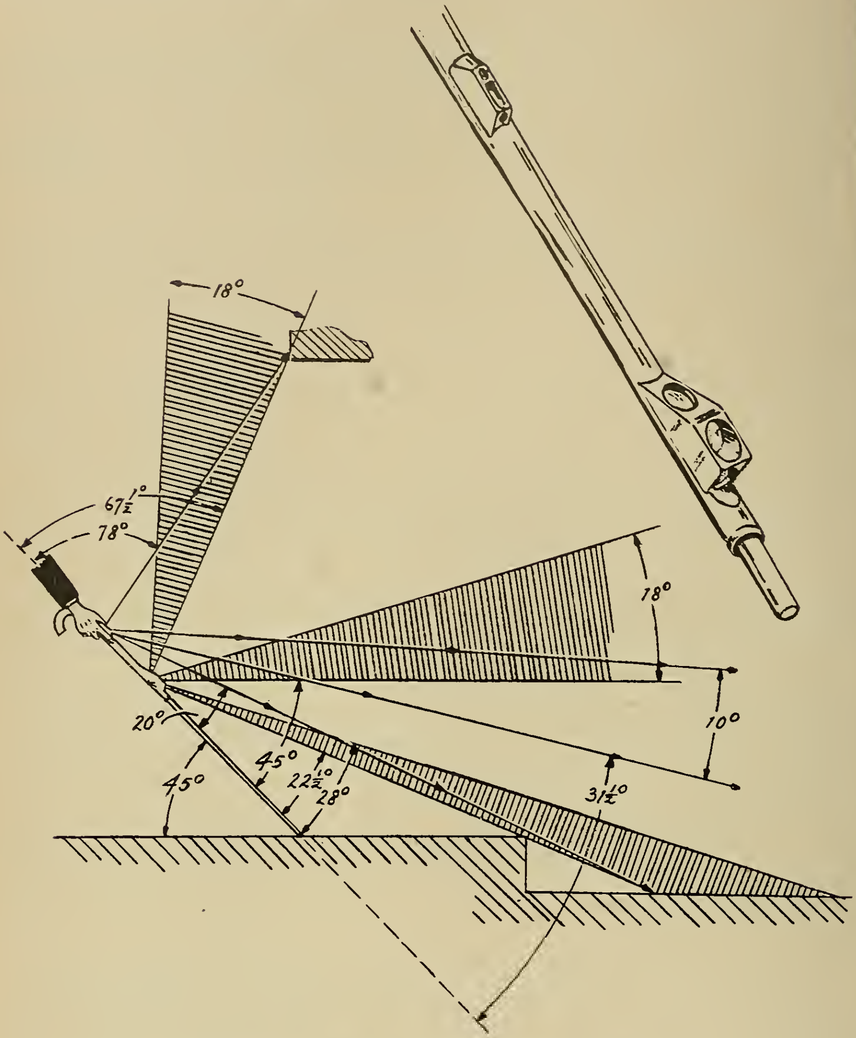

Figure 10.—C4 Laser Cane beam coverages.

Light Sources

The original Signal Corps optical triangulation guidance device used a continuously burning incandescent lamp as its light source, the reflection of which by an obstacle was picked up by a lead sulfide photodetector placed in the image plane behind the receiving lens. Major improvements required fast response, high brilliance, small size light sources coupled with high sensitivity, low noise photoreceivers. In terms of brilliance it is hard to better an incandescent lamp, but its response time is so slow that, for the quantities of light required, a mechanical chopper is necessary that is heavy, possibly noisy, relatively inefficient, and somewhat unreliable. Modulating the light in this way also wastes light power while the lamp is occluded by the chopper. With a 50 percent duty cycle half the lamp power is wasted. Furthermore, if the light can be made to recur in short bursts instead of going on and off in a 50 percent duty cycle, radar system analysis shows that an improvement in signal-to-noise ratio can be anticipated. For equal pulse energies, the improvement is proportional to the reciprocal of the square root of the duty cycle. The foregoing considerations led us to search for pulsed light sources of suitable size, spectral output, and power. Numerous types of low pressure glow discharge lamps were investigated, including Neon, Argon, and Xenon filled types, with crater and rod, dual rod, and flag-type dual rod with auxiliary types of starting electrode constructions. All of the pre-cane devices used such lamps.

As soon as noncoherent, gallium arsenide light emitting diodes became available in 1963, we studied them. While they had a smaller conversion efficiency than the Xenon filled discharge lamp, they also had the clear advantages of smaller size and easier control. Furthermore, we expected that the coherent or lasing gallium arsenide diode would soon be developed to where it could be used at room temperatures instead of requiring liquid nitrogen cooling. Feasibility of this light source was proved by constructing the first three-channel cane discussed above. Thus, when economical solid state room temperature lasers became available, we were fully prepared to take advantage of them. Perhaps their most important single advantage to the project is their extremely small spot size (width) and the consequent possibility of easily producing a well-collimated beam from them, which allows the use of a quite small optical system.

The General Electric Type H1D1 laser is the most powerful unit of its type currently available, so it is the laser used in the C4 cane. Its relatively high energy conversion efficiency, coupled with its fast rise time, allowed us to build a pulse system with a good signal-to-noise ratio and good overall efficiency, because of the extremely small duty cycle of 250,000 to 1 that can be achieved.

Mechanical Design

In approaching the design of the C4 cane, it has been recognized that the blind traveler can travel satisfactorily without an electronic cane. The distant warning features simply make it easier to train the newly blind and make traveling more relaxed for the seasoned traveler. Thus it is necessary that the electronic cane function satisfactorily as a mechanical cane. If it is too heavy, if it reacts in an unaccustomed fashion when used as a probe, or if it looks too peculiar, it will not be used. All of the accumulated experience gleaned from testing of the earlier models by blind travelers was used in doing the human engineering on the C4.

Major attention was focused on trying to achieve low weight and good balance. To this end the whole functional section was constructed of magnesium, and the batteries and other relatively heavy components were mounted in the crook to move the center of gravity up as high as possible. Since the bottom half contained no electronics, it could be made of any material that would help duplicate the "feel" of the conventional long cane. Magnesium was found to be too "springy"; while aluminum was heavier than desirable. Basically the required material should have a high modulus of elasticity to reduce the feeling of "whip"; it should have a low density; and it should have a high ultimate yield point because of the danger of breakage when the cane sticks in a grating or gets caught in a car bumper. The search ended with a new plastic laminate developed for aerospace use. The material is a reinforced epoxy in which each tungsten reinforcing fiber has been coated with a thin layer of boron. The final material has a modulus of elasticity of about 60×10^6, as compared to approximately 15×10^6 for conventional fiber glass reinforced epoxy, 30×10^6 for steel, and 12×10^6 for aluminum in the grade used in present canes and for magnesium in an alloy readily available. It also has a low density in the formulations of interest. The lower section used in the cane is approximately 50 percent lighter and 6 times stiffer than the most suitable magnesium tube. Furthermore it could be made with a taper, which shifted its center of gravity 2 in. above its mid-point, thus helping to raise the overall balance point for the cane.

The cane tip was made of nylon. Experience with the long cane showed this material to have good wear and friction characteristics.

Almost all cane users would like to have a collapsible cane because the 4 to 5 ft. length of the long cane makes it awkward to store under many conditions (e.g.; restaurant, bus, waiting room). However, it is hard to construct a cane that will have several joints, be rugged, weigh little, be quick to assemble, and transmit "sensitivity" from its tip. It was felt that one joint in the center of the cane would be a workable compromise. The O-ring joint shown in Figure 11 turned out to be satisfactory. It was compared to several other designs for durability, lack of play, lightness, and transmission of vibration ("sensitivity").

Electronics

Figure 12 shows a block diagram of the cane electronics.

A ringing choke-type DC-to-DC converter drawing power from the 12-volt battery and operating at an audio frequency charges an energy storage capacitor to about 550 volts in 20 to 25 milliseconds. A spike-producing relaxation oscillator employing the avalanche mode of a transistor, which operates at 40 Hz and is synchronized with the repetitive chargings of the capacitor, is used to trigger a silicon-controlled rectifier that discharges the capacitor through the three lasers in series. The lasers produce coherent light of about 3 to 10 watts of average light output pulse power until the

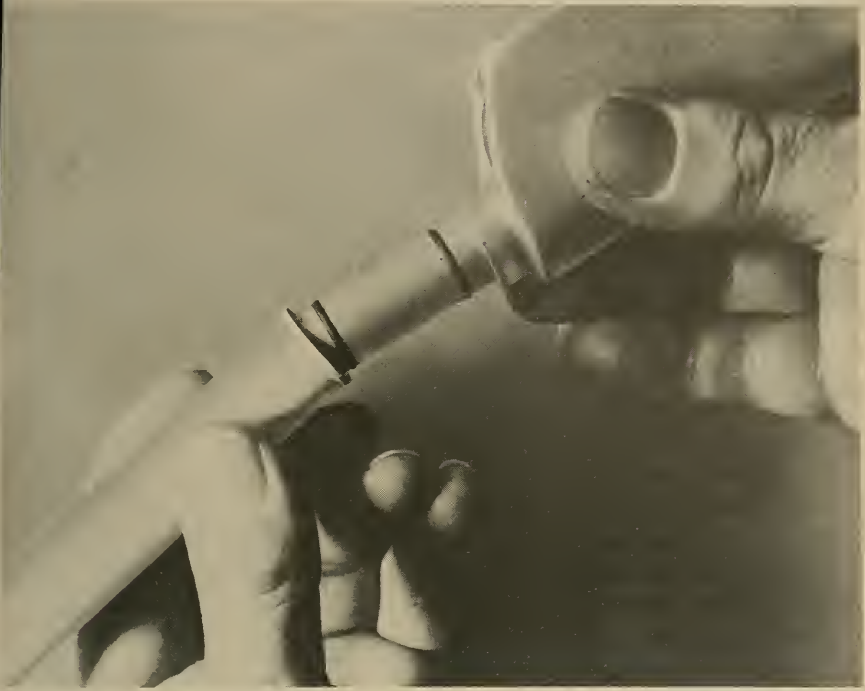

FIGURE 11.—C4 Laser Cane removable joint.

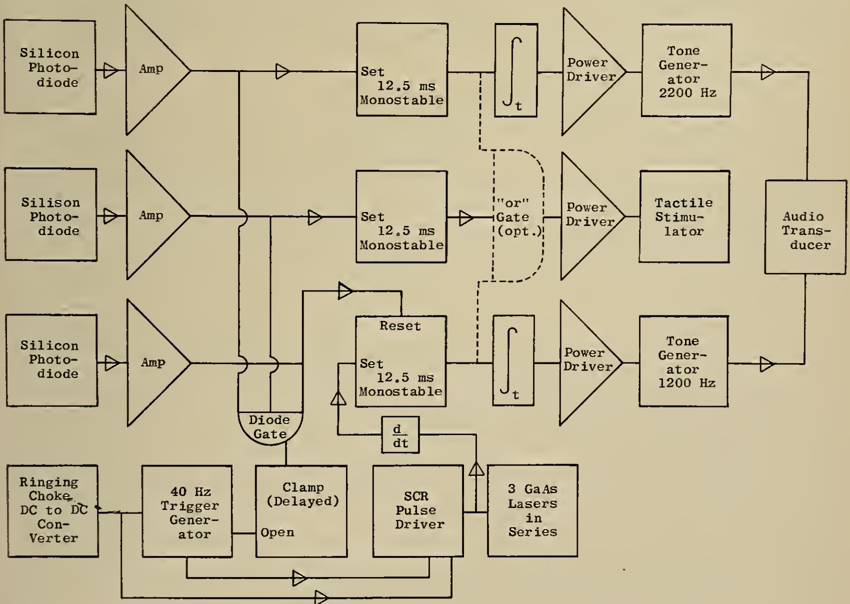

FIGURE 12.—C4 Laser Cane electronic block diagram.

current supplied by the capacitor falls below the lasing threshold of about 90 amperes.

It is interesting to note that the ringing choke supply was originally designed to operate the Xenon flashlamp used in the G5 model obstacle detector, and considerable effort was expended in its development to minimize power loss and weight. It developed that, when the light source was changed to a gallium arsenide laser, this supply was still useful.

The three silicon P–N junction photodiodes, made especially for this purpose by Philco, are each connected to the input of a five-transistor amplifier which has a bandwidth nominally extending from 10 kHz to 3 MHz and a typical gain of $100dB_{vg}$ (10^5 volts per volt). The maximum gain is sufficient to cause triggering of three monostables by 10 to 12 microvolts photodiode noise, one of which is connected to the output of each amplifier. The amplifiers are designed with complementary transistors so that negligible power is used when they are not passing a signal. All three channels are gated by diode steering (AND gates) driven from a switching transistor which is operated by a signal derived from the laser pulse drive circuitry. The gating pulse is delayed a few nanoseconds to take into account the light pulse travel time and the delay time through the electronics. The gate is used to prevent the system from responding to transient flashes of light. Since the gate is operated for only 100 nanoseconds out of each 25 million nanoseconds (repetition rate of 40 Hz), a ratio of 250,000 to 1, the likelihood of a random transient being detected is almost nil. In fact, there is rarely any interference when two such systems are pointed at one another. Detection of 60 or 120 Hz signals from artificial light sources is further prevented by the 10 kHz low frequency cutoff of the amplifiers.

After gating, each amplifier output operates a complementary one-shot multivibrator, which draws no current when not triggered. The output pulse of each is adjusted to 12.5 milliseconds, so that detection of a single light pulse will give a stimulus of this duration. This increases the likelihood of human response to the stimulus. In the "straight-ahead" channel the multivibrator drives the stimulator through a single "saturated" stage amplifier. The stimulator thus operates at a 40 Hz rate with a 50 percent duty cycle (12.5 milliseconds). All three channel monostables had originally been set to 12.5 milliseconds so that their outputs could be combined (OR gate) to cause operation of the tactile stimulator by all obstacles. Later experimentation showed that most users found less confusion if the tactile stimulator was operated only by the "straight-ahead" channel. The output of the "upper channel monostable pulse is stretched to about 200 milliseconds by an integrating-type stretcher. The stretched pulse, through a complementary power driver, turns on a 2200 Hz square wave uninjunction relaxation oscillator. The "downward" logic uses elements similar to those of the "upward" channel, but with "reversed" logic. Thus the monostable is started by a differentiated spike derived from the laser pulse driver. The monostable is very promptly reset if a pulse is produced by the "downward" amplifier, thus producing no discernible output. However, if no pulse is returned through the amplifier, the monostable remains on for its set period of 12.5 milliseconds. As in the upper channel, the monostable pulse is stretched to 200 milliseconds and, in this case, turns on a 1200 Hz oscillator. The outputs of the two oscillators are coupled to a barium titanate piezoelectric output transducer, the response of which is peaked and broadened by an inductor.

Power to the whole system is supplied by a 12-volt 225-milliampere-hour nickel-cadmium rechargeable battery. The lasers and associated drive circuitry consume .3 watt, the electronics another .1 watt, while the stimulator and tone generators together take an additional .3 watt. Thus the whole system, when running with all three channels producing outputs, consumes .7 watt. The average power consumption in typical usage appears to be about .5 watt. Under normal use it has been found that the battery will operate for about 5 hours before requiring recharging. As it discharges, the system loses sensitivity and the repetition rate decreases. The laser drive energy storage capacitor makes an audible ticking noise; thus an alert user can hear the slowing of the repetition rate. The battery recharge rate has been set to half the discharge rate, so that it takes 10 hours to recharge after fully discharging. The charger is a small unit that plugs into any AC line and connects to a socket in the cane handle through a small, phone-type plug. The charger is transformer-coupled and produces a voltage which is too low to constitute a shock hazard. It may be left connected even after the battery has achieved full charge without causing damage.

EVALUATION

After the Model C3 cane was completed in December, 1967, it was taken to eight mobility training centers on the East Coast and in the Midwest in order to collect comments and reactions before designing and building the "final" model. An estimated 50 people used the cane indoors and out for periods of time between 10 minutes and 1 hour each. The results of the study are summarized below.

Performance as a Conventional Cane

1. *Appearance.* Judged to be satisfactory and non-attention-getting, but considered to be too "masculine" to please the ladies. The exaggerated appearance of the crook (thickness, radius of curvature, and length of back portion) tended to rub in the fact that this is indeed a cane with its "badge of blindness" connotation.

2. *Feel.* The feel of metal was judged to be not as pleasant as plastic, cloth, or rubber. Those with sweaty hands commented on this aspect particularly. The thickness of the electronic portion was commented on favorably

by most people, but unfavorably by one man with small hands and by several ladies.

3. *Flat.* All who were asked considered the flat to be valuable as an orienting surface and to have a pleasant feel about it, though some felt that, if there was any advantage to it, the flat area could be narrower. The location of the switch in the flat area was considered good, but it was suggested that it be turned at right angles to its present position, so that if the finger slipped as a result of the cane's banging into something, it would not result in turning the device off or on accidentally.

4. *Center Joint.* It was considered desirable to have means for folding the cane in half when not in use. However, rigidity of this joint is quite important, and this rigidity must be achieved without increasing the weight of the lower half of the cane. No one seemed to feel too strongly on this point, perhaps because all visited were used to using the present Typhlocane, which is noncollapsible.

5. *Weight.* Perhaps because of the large diameter and general bulky appearance of the upper part of the cane, everyone was surprised at how light it seemed to be. One small man and the women were exceptions to this statement. Those who carried the cane for a ½ hour or more were asked, "Well, how does it feel now?" The general response was that it was certainly considerably heavier than the cane they were used to, but if it was absolutely necessary, the weight could be lived with for the proffered advantages.

6. *Balance.* Again, almost everyone evinced surprise at the balance. Some made tests to compare it with the Typhlocane. The most interesting test was made by one brave blind trainer who raced full-tilt toward a downgoing flight of steps to find out if the cane tip would fall over the edge of the steps before he did! He concluded that in this respect it seemed to be as "fast" as his regular cane. If the cane tip was raised 2 or 3 in. above the ground and then allowed to fall, it would bounce two or three times more than a Typhlocane undergoing the same test. This effect is probably a combination of balance plus mass or moment of inertia.

7. *Tip.* No effort was made to determine whether or not a tip made of some other material than the nylon tip on the present cane would have been better. This nylon tip is the same as that on the Typhlocane, and, since most of the people contacted were Typhlocane users, the question was not discussed.

Electronic Information Outputs

1. *Stimulator.* The stimulator was judged by all to be quite satisfactory in feel, power, and frequency. Those who used it outside with gloves on found no difficulty in sensing the stimulator through the glove. The position between the top laser beam and the stimulator seemed to be short enough to

accommodate the smallest hands encountered, but with the smallest two or three hands it was close.

2. *Tone.* The range of tone intensities seemed adequate, though in a noisy outside environment the maximum volume still may not be enough. Four people were not able to hear the high-pitched tone, and there was confusion on the part of some as to whether the high or low-pitched tone was being sounded. This confusion did seem to disappear with continued use.

3. *Telemetry.* Almost everyone felt that it would be useful to have the tones available in hearing-aid eyeglasses, provided no wire had to connect the eyeglasses to the cane. One or two felt that a tone in this location would cause serious masking of conventional auditory cues. Interestingly enough, these people were familiar with the Kay device, and, even so, they had this feeling.

Individual Channel Performance

1. *Dropoffs.* Almost everyone felt that this was by far the most important feature of the cane. Some went so far as to say that if the other two channels were missing, the cane would still be quite worthwhile. It was felt by these people that the most serious failing of the conventional cane and also of the Kay device was its lack of ability to detect dropoffs as far ahead as the user would wish. One person felt that overhangs were more important than dropoffs, and that unless the dropoff detector could detect even small dropoffs (e.g., large cracks in the sidewalk), it would be better not to have it for fear it would fail to give warning of a small dropoff. He felt that people were as likely to trip and fall over small dropoffs as they were over large ones. His experience, however, was with training old people exclusively, and he felt that this might have some bearing on his point of view. Most others felt that small dropoffs would not be serious, but that it would be desirable to detect a 6 or 8 in. curb. (The C3 cane would not detect a dropoff of less than a foot under any condition.) The C3 cane contained one technical fault which was corrected in the next model. If there were a light-colored wall only 2 ft. behind the dropoff, the signal returned from this wall would make the dropoff indicator fail. Dropoff detection is supposed to be achieved by optical triangulation. However, by suitable adjustment of the amplifier sensitivity control, it was found that appreciably more sensitive performance could be obtained, making use of changes in reflectivity of the dark streets and dark gutters as compared with the generally lighter colored sidewalks. So it would seem desirable to make such a sensitivity control available, at least in the models to be evaluated, in order to see whether a sophisticated user could get further information from this characteristic.

2. *Straight-Ahead Detection.* This channel seemed to prove valuable for many things beyond the detection of obstacles. It was found useful for following shore lines, for walking a straight line down a corridor, for following a person a few feet ahead, and for finding narrow doorways well before

the cane tip found them. The general effect of all this was to noticeably increase the "grace" with which some people walked with the cane indoors. This is a very tricky matter to evaluate, however, inasmuch as all of the people using the cane were either experienced blind travelers or experienced mobility trainers and thus could do quite well in a familiar, nontension-provoking environment anyhow. A test was performed once or twice, however, in which the same user walked the same course using the cane with the electronics switched on one time and off another, and it is on the basis of these observations that the comment about graceful walking is made.

One person found the cane unusually useful for locating "the trough in the snow" through which sighted people were threading their way. It was not clear whether the straight-ahead or dropoff channel was being used for this purpose, but it was very clear that, with the cane turned off, the same performance was not achievable.

3. *Overhangs.* In principle, almost everyone agreed that it would be quite desirable to have advance warning of an overhang. But when people tried the cane, there was also almost universal agreement that this channel was the least important of the three. Some, in fact, found it confusing, and one or two actually undesirable. It was concluded that detection was set too far in front of the cane, so that not only was warning given of an overhang, but also, if an object came within a foot of the cane tip, warning was also given with the same high-pitched beep of the wall or other obstacle that had already been detected by the straight-ahead channel.

As a result of this evaluation, the following changes were made on the present (C4) model:

1. The weight was reduced from 2½ to 1⅓ lb.
2. A joint was placed between the upper and lower sections.
3. The diameter of the upper section was reduced from 1.2 in. to 1 in.
4. The upper and lower nacelles were substantially reduced in size.
5. The on/off switch was repositioned to reduce the likelihood of accidental actuation.
6. The laser discharge capacitor, which was quite noisy in the C3, was quieted to eliminate its drawing the attention of the user or those passing by.
7. The upward channel stimulator tone was lowered by an octave to help those with high frequency hearing loss.
8. Optical and electronic crosstalk between channels was eliminated.
9. A sensitivity control was installed in the downward looking channel.

THE FUTURE

Currently, several copies of the Laser Cane are being fabricated to be tested by blind travelers and mobility trainers. The results of these tests will determine what changes should be made in design and what techniques will prove valuable in using the cane.

As for the future, it may be viewed through laser glasses! The time is nearing when it may become technically feasible to build an entire system into such a device. This would have the advantage of leaving the hands completely free and allowing the traveler to scan the scene ahead in a more "normal" way. The glasses should contain two channels, one downward looking, so that holes could be detected without any special effort.

Beyond this, it is our opinion that more will have to be learned about how the human operator assimilates and uses information before there will be much point in designing devices that can produce more information.

It should be pointed out that canes, flashlights, and glasses all form part of a general armamentarium that should be available to the user to suit the individual situation. No one instrument can be reasonably expected to be a panacea for all mobility problems.

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The engineering of the cane has been carried out by D. Ridgeley Bolgiano, E. Donnell Meeks, Jr., and the author. Past work leading up to the cane development was engineered by Dr. Don DeVault, who, in turn, picked up the work of Daniel Berger and Randall Thomas in addition to the author. Much thought, effort, and materials have also been contributed through the years by concerned and talented machinists, technicians, and vendors.

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SHORT TERM FIELD EVALUATION OF TYPE 8A9 ULTRASONIC AID FOR THE BLIND [a]

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INTRODUCTION

In this report I present a short term analysis of a variable pitch, echoing device used as a mobility tool for the blind. This device, the Kay ultrasonic mobility aid, Type 8A9, is manufactured by Ultra Electronics Limited, Western Avenue, Acton, London, W.3, England.

Dr. Leslie Kay of Christchurch, New Zealand, first introduced the concept of this frequency modulation ultrasonic mobility aid around 1960. He based this aid in part on the analogy of the bat orientation system—a principle of ultrasonic radiation and detection that is used by bats while traveling in darkness to avoid hitting obstacles and to find food. The device soon afterward receved wide scientific and popular recognition.

DESCRIPTION OF DEVICE

The 8A9 Kay ultrasonic aid for the blind consists of the following:

1. A torch unit complete with rechargeable battery
2. An earpiece complete with a cord and earclip
3. A spare rechargeable battery
4. An extension lead to connect the torch with an external 9-volt dry-cell battery (for use in circumstances where battery charger cannot be operated)
5. A leather carrying case for the torch unit, battery, and extension lead from the torch to the battery
6. A battery charger
7. A leather case for the battery charger

Editorial Note: The torch is a transmitter-receiver unit shaped like a flashlight with a long handle. It contains transistors, correlated components, and ultrasonic transducers in the forward part which are protected by an external wire mesh. When in operation, the torch transmits a beam of ultrasonic energy. This beam upon striking an object is reflected back to the device and is picked up by the receiver. Since this beam is ultrasonic and cannot be heard by the normal ear, the frequency is reduced to within the normal range of hearing and becomes an audible sound. The pitch of the sound that is produced is actually proportional to the time interval between the sending and receiving of the beam. This interval varies in accordance with the distance of the object that is detected. An object that is detected at close range, therefore, will return the beam sooner, the interval between sending and receiving will be shorter, and the tone of the output signal will be in a lower pitch. For objects detected further away, the time interval increases and the pitch of the tone becomes higher. The variable sounds produced by the energy returned from objects detected may be interpreted by the user to determine approximate distance, texture of the object, and contour of the object.

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[a] The work for this report was performed by the author independently.

[b] A former Navy man, the author is now employed as an engineer for an industrial manufacturer. Totally blinded in 1966 as the result of an automobile accident, he has since completed 15 weeks of rehabilitation and mobility training at the Greater Pittsburgh Guild for the Blind and 30 days training at Seeing Eye, Inc. To date, he has been working constantly with both cane and dog guide.

EVALUATION PROCEDURE

The apparatus was assembled and operation of the controls was verified to be in good working order. The first work with the torch unit was done in the interior of my home. Work was principally concentrated on locating objects and openings and estimating distances. Outside work began on my residential lot, which is heavily wooded with trees and bushes. A sighted companion was used during the initial outside trial. With a fair degree of confidence established in the instrument, independent trials were conducted on the residential lot and one quarter of a mile of the surrounding neighborhood. Battery life and charging procedure experience were accumulated during these trials.

Independent travel, utilizing the torch as the only mobility aid, was conducted for a variety of situations involving travel along paved asphalt roadways, equipped in the main with curbing but no sidewalks. Experience was gained in discriminating and locating landmarks. Usage was broadened to a greater degree by independent travel in known areas remote from the immediate neighborhood, such as parking lots, random traveling with no recognizable travelways, narrow, steep exterior stairways, and complex interiors complete with naturally located objects and people. The torch unit was used for mobility in the working business environment and it was exposed to only a narrow variety of environmental conditions. The majority of these conditions included warm, dry weather in either daytime or nighttime. However, a minor amount of work in cool, damp, and rainy environments was performed.

Total estimated usage time was about 25 hours. Total time was accumulated over a 6-month period consisting of approximately 1 hour of usage per week. Weekly usage was spaced at intermittent intervals of 20 to 30 minutes per trial.

All discussions, remarks, and conclusions were drawn from the above experience.

DISCUSSION

Perception of Objects

Isolated Objects

Objects with no echoing background can be easily located and traced utilizing either short range sounding (under 7 ft.) or long range sounding (up to 20 ft.). The location of an isolated object is virtually exact since a high contrasting sound is detected when the beam encounters the edge of the object. With no echoing background the rebound signal is practically nil. Regular objects (such as autos, buildings, poles, etc.) can be easily traced for exact outline of form. Irregular objects (such as trees, bushes, people, etc.) can be readily judged for general contour (width, height, and general outline).

Superimposed Objects—The Detection of Objects with a Reflective Background

The accuracy of detecting objects with a reflective background is proportional to the distance of the object from its background. For example, it is practically impossible to detect a flat plane such as a sign that is mounted closely adjacent to the side of a building. As the offset distance of such an object increases from its background, the contrasting echo is more readily detectable. The greater the degree of contrasting pitch of the echo, the more accurately the superimposed object can be located and traced. The same remarks with regard to form as apply to regular and irregular isolated objects apply to superimposed objects.

General

The prime requirement of safely detecting an object, before the user collides with it, is in the main fulfilled. There remains the problem of completely scanning the potential collision area. Slow, careful scanning, such as an "X" pattern, in front of a user yields practically 100 percent safe mobility. However, this slow method of progress is not generally acceptable to the well-mobilized blind person and would be utilized only in areas that are totally unknown or known to have obstructing objects that might strike the user above the waistline. Travel over more conventional travelways such as sidewalks, roads, corridors, etc., can be conducted with a fair amount of speed (1 to 3 m.p.h.), while utilizing a short horizontal sweep of about 2 to 3 ft. in width and aimed at a ground level approximately 4 to 5 ft. in front of the user.

This method of scanning the travelway was found to yield auxiliary information such as projecting branches and other minor and major objects located below the waistline. Even such minor projections as a weed in the travelway could be distinctly detected in time to avoid collision.

As with most mobility tools, the unit's best usage as an object detector depends on a great deal of concentration while traveling. Since the receiving earpiece covers one ear and the user's mind is intently concentrating on this signal, all other audible sound information is very definitely reduced to secondary importance. I would estimate that one loses as much as 30 to 40 percent of available secondary sounds falling on the single exposed ear. This loss generally consists of minor, low volume background sounds. Any background sounds of medium to high volume consistency are readily discernible. Despite this masking effect, the auditory system seems uniquely able to discern and register any sound of primary importance, such as potential safety hazards, etc.

Static observation yields a fascinating amount of information to the user. The unit provides object detection by scanning in a far greater degree than any other apparatus used to date. The user knows for a considerable distance where open spaces exist, where objects are located and their general form. He can measure each with respect to another and virtually obtain an audible pattern of his surroundings. Only a sighted observer could exceed the unit's performance in this respect.

The user will find it fascinating to realize that this information can now be "read" on an independent basis. To know the width, height, and outline form of trees, buildings, etc., and each in relationship to the other, is an exciting revelation. An interesting auxiliary piece of information under the topic of object detection should be noted—the fact that overhead wires can very sharply be located and the direction in which they are strung is readily discernible. This could provide an important locating and directional device for persons in unfamiliar territory.

Distance Measuring Ability

Short Range

With practice the user can become quite accurate in measuring ranges to objects less than 7 ft. away. At a distance of 7 ft., estimating accuracy was good for ±1 ft. A shorter range of about 4 ft. generally yielded an accuracy of about ±6 in. At shorter ranges distance estimating ability seems to be of lesser importance than object detection.

In explaining this point of view, take the example of a user utilizing a typical 2 to 3 ft. horizontal scan at a directed range of 4 to 5 ft. As the user approaches a closed door mounted flush in a wall he will detect the wall at about a 6 ft. range. With the range continuing to close, at about 3 ft. the user will simultaneously direct the torch beam at waist level and fairly accurately locate the door knob, since it represents a projecting object about 3 in. offset from the door. At this close range, object detection generally becomes more important than range estimating, since either the object is to be located for use or veered around to avoid collision. If the user intends to locate the object for use, he will continue to close the range and will be able to estimate contact within ±2 in. The distance measuring ability at very close ranges (under 1 ft.) is not as accurate as one might suppose. One would think that the short range would give extremely accurate estimations of about ±½ in., but in truth the pitch becomes such a low frequency tone that discrimination of tonal variations can only be estimated to about ±2 in. These remarks are all related to a mobile person. If one should stand and estimate static distances, he can probably increase his accuracy as much as 50 percent.

Long Range

The estimation of distances utilizing long range echoing is poor. However, there seems to be no real reason to desire a high degree of accuracy while utilizing this type signal. Its primary value seems to be in object location, such as landmarks. The fact that landmark location is very accurate and that an estimate of the distance to the landmark is somewhere between 10 and 30 ft. is very useful information. As the user closes on such objects he can commence distance estimating when within the short range capability and is then working quite accurately in both locating and estimating the distance to the object.

General

The ability of the instrument to indicate distance as a function of varying pitch provides the user with more than just a distance measuring device. It allows him to obtain a three dimensional aspect of objects. As an object is traced for contour, the user can also discern, due to pitch variations, the form of the object. For example, a tree can be located with respect to the user, its shape determined by scanning. While scanning, the pitch will vary as the beam sweeps across the object, telling the user what portions of the object are closer to him and what portions are farther away from him. A three dimensional auditory picture is thereby obtained by the user.

Discrimination of Material

There seems to be a certain amount of ability to determine the difference in some materials. In particular a strong, short, and hard sounding echo is obtained off glass surfaces. This is especially noticeable when a fairly large area of glass is set flush into a surrounding wood surface. The surrounding wood surface does not give as strong a rebounding signal as does the glass. Contrasting surface textures also offer some differences in echoing. A flush mounted smooth garage door surrounded by a rough exterior house trim such as shingles, etc., offers a much stronger signal rebound than does the surrounding texture.

Many attempts were made to discriminate between an asphalt driveway surface and the lawn surrounding it. This is important in mobility so that the user may travel an intended path. The typical sweep speeds synchronized to the user's stride rate did not yield any differences between the two surfaces.

However, it seemed that as the sweep speed was increased to about double the typical stride rate, a small amount of difference could be detected as the beam crossed from asphalt to lawn and straight line travel was considerably improved utilizing this method. The same effect was observed while traveling along the edges of asphalt pavement having no sidewalks but equipped with curbing. The ability to maintain contact or location of the curbing was fairly accurate at slow speeds (1 to 2 m.p.h.) and scanning fairly close to the user's feet at a range of about 2 to 3 ft. However, as mobility speed increased (2 to 3 m.p.h.) and the range extended to about 6 ft., accurate location of the curbing on each sweep was very poor at the regular sweep speeds. By doubling or tripling sweep speeds it was found that contact with the curbing could be maintained to a far greater degree. This effect is undoubtedly due to a greater transient dynamic as the beam passes over the curb. The faster sweep rate produces a more discernible contrast between the slight variations in pitch. Undoubtedly, the additional "looks" at the curbing also helped to reinforce the sensation of its location.

Certain shapes of smooth objects were found to give a distinctly different rebounding echo. For example, small diameter iron pipe rails along stairways are quickly and accurately located, due to their characteristic echo. The echo from such a surface is best described as a small, hard, short ping as the beam scans across it. Telephone wires, lamp posts, and telephone poles also reflect this type of characteristic sound. It is felt that since all of these objects are of a circular form, the echo obtained from them may be more due to their form than to their material. In any event, this characteristic sound serves as a valuable addition to the auditory spectrum.

False Echo Analysis

Since the transmitting and rebounding signals are in a wave form, there exist certain areas that tend to reflect a reinforced signal which is received by the user as a much stronger contrasting signal than the typical areas surrounding it. The user may determine in error that this stronger signal is indicating some object other than the area being scanned. In particular, while scanning along a corridor the rebounding echo from the sides of the corridor give a fairly weak signal, due to the low angle with the wall. While concentrating on this weak signal, the user will generally encounter the end of the corridor, at which point a corner on each side is located. When the beam strikes into the corners they reflect a very strong echoing sound, even stronger than the wall at the end of the corridor. At first this contrasting signal tends to confuse the user, but with practice he can begin to interpret this false echo for what it really represents, that is, a corner or projection that allows echo reinforcement. In this manner the user can stand in a room, and by scanning all four walls he can very quickly locate and estimate the distance to each one of the four corners, giving him good orientation to his surroundings.

Another type of signal that may not technically be called a false signal, but is certainly one that tends to be lost to the user, is the sudden appearance of an object crossing at a very short range, such as a person moving rapidly in front of the user while the user is working at the more typical 5 to 7 ft. range. The sudden, very low frequency echo rebounding from the person tends to be hidden or ignored in the higher frequency echoes from the long range material. This same type of hidden or ignored signal is often encountered while traveling in close proximity to other persons. When the user does detect this sudden encroaching, very low frequency signal, about the best that he can do is to stop abruptly to determine what object has suddenly located itself in his path. This of course leads to short halting advance in travel. The inability to detect people moving obliquely from the side or rear into the scanning beam is of course no fault of the instrument itself, but certainly does not allow much freedom for traveling among persons under crowded conditions.

As mentioned before, the incident angle at which the beam strikes material being scanned affects the strength of the rebounding signal. The weak signal obtained when traveling at good speeds (3 to 4 m.p.h.) due to the user scanning at maximum short range and at a fairly high sweep rate causes detection of short dropoffs to be very difficult. This can be a serious difficulty in that curbs cannot be accurately detected at intersections. It is more than probable that the user will step off the curb and discover it by kinesthetic rather than auditory detection. However, this may not be too important in the light of such facts that only the agile user would be traveling at such speeds and probably experiences the very same thing when using a mobility cane. For example, my mobility cane measured according to prescription stride is a length of 42 in., but as my experience increased with the cane and my travel speed increased, I soon began to overrun curbs. My cane was first extended to 51 in., then later to 54 in., in an endeavor to overcome this difficulty. Even with the rather lengthy additions, I still ofttimes overrun curbs when traveling at high speeds. Obviously the detection of curbs or down steps is greatly enhanced if the user can anticipate such down steps in advance and slow his approach so that a more accurate scanning can be executed.

CONCLUSIONS

I am basing all my conclusions on the fact that my evaluations are of a short term period and will undoubtedly be altered somewhat as depth of experience is gained. I am also very aware that the successful utilization of this apparatus depends upon a fair degree of hearing acuity. It is my opinion at this time that the apparatus represents only a fair means as a primary mobility tool. It does not compare in mobility accuracy to the mobility cane or dog guide. However, it does offer some major advantages and benefits.

A considerable amount of environmental information can be realized while utilizing the apparatus. This can be of such immense satisfaction to the user that he could come to prefer it to the above mentioned mobility devices. This preference would have to go before a desire to perform at reasonable speeds in a high degree of accuracy and safety. It is doubtful that the person intent on traveling to and from particular locations for specific purposes would find the instrument satisfactory. The advance rate would be too slow and embarrassing dislocations and collisions would probably result. However, in the hands of a user whose intent is merely walking for pleasure, he would find such an instrument a very interesting and satisfactory device during his casual strolls.

The instrument is also quite good when used in interior, fairly uncrowded residential environments. Its ability to accurately locate objects, estimate distances, and give considerable background information greatly enhances its usage for this purpose.

I cannot help but theorize as to some tremendous advantages that could be gained from utilizing such an instrument that might be equipped with as much as triple sending and receiving devices as now employed. Each set of heads might operate over a different frequency band. Such an instrument might yield an extreme amount of information of all the area being scanned and would reduce the scanning chore considerably. It is reasonable to assume that one might obtain a three dimensional sonic picture of the scanned area. I would therefore recommend additional work in this area if thought practical that such an approach be undertaken.

THE VISOTONER: A PERSONAL READING MACHINE FOR THE BLIND

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While the Chicago area was being inundated by the great snow storm of January 1967, I had one of the most rewarding experiences of my life. It all started three years ago when I began to learn to use the Veterans Administration's Battelle Optophone (1). Later I used the first Mauch Visotoner optophone. At first I could check my own touch typing and later I could read typed correspondence. A greater feeling of independence arose when I was able to use the reading machine in conjunction with other skills to complete business transactions independently. For example, I now read many utility bills myself and make braille notes, type checks and envelopes, read my typing, and check the legibility and function of the pen. (The reading of handwriting is not now feasible.) I can mail the check confidently and later read the bank statement and canceled checks and compare them with my original braille notes. I find that the reading machine adds to the value of braille, typing, and language skills. As my skill improved, the list of reading tasks increased but attempting to read the dictionary had always resulted in a hopeless "blur."

Then, just as the great snow began to fall, the newly redesigned Visotoner arrived from the manufacturer, Mauch Laboratories, Inc., Dayton, Ohio (2). The Visotoner was developed under a research contract with the Prosthetic and Sensory Aids Service of the Veterans Administration. Since I had used other optophones, I was asked to try the new machine.

So I sat down with a stack of mail and the new Visotoner. Most of the return addresses were amazingly legible. While reading the table of contents in a magazine, I was so impressed with the "fidelity" with which this machine "sees" the print that I decided to read a whole article. I felt compelled to reach for the dictionary and sure enough, it came alive. To be sure, there were times when deciphering unfamiliar diacritical marks used in dictionaries became necessary, but now I can use the dictionary when the need arises.

Our faithful volunteer sighted reader could not make it through the snow that week but since then her services have not been needed regularly because

I have been able to meet my urgent reading needs. For the first time, I felt I had acquired a bit of synthetic eyesight.

HOW DOES THE MACHINE "SEE" THE PRINT?

The Visotoner contains a vertical column of nine photocells, an optical system, and the electronic circuits to generate a different audible tone for each photocell while it is "seeing black."

We cannot say that the machine reads—rather, it presents the letter shapes as tone patterns. As it is moved along a line of print, the nine-tone output is usually heard in an earphone. Each letter or other symbol has its characteristic tone pattern. If the two lowest tones are heard, it means that the letter extends below the line. Each of the five middle tones responds to its assigned band of print encompassing the so-called "x" height of the letters. If the two highest tones sound, it means there is print extending above the "x" height. For example, reading a hyphen results in a steady tone. The letter "I" consists largely of a chord and the letter "V" makes a "wavy" sound.

The user must learn to interpret these tonal patterns as letters and words on the printed page. This involves a rather lengthy learning process similar to the experience of a sighted child learning to read ink-print. The 200-hour course of training developed at Battelle Memorial Institute, Columbus, Ohio, uses text in ordinary print and some tape recordings.

The Visotoner has a variable-magnification optical system which permits the user to select the proper magnification for reading letters printed in 7 to 36 point type. A lamp brightness control is also used. The machine with its battery and earphone can be carried in its leather case the size of a hardcover textbook. During training and when reading for long periods, it is advisable to use the machine with its tracking board which Mauch Laboratories has named the Colineator. All equipment mentioned, plus a battery charger and spare battery, fits into a small, specially designed attaché case.

PROGRESS REPORT

Currently, my work in the Central Rehabilitation Section for Visually Impaired and Blinded Veterans, Veterans Administration Hospital, Hines, Illinois 60141, includes testing, demonstrating, and teaching the use of reading machines. The work has only begun, for now production models must be perfected and techniques for teaching the skill need refining. Much also needs to be learned about the usefulness of the equipment and the kinds of people who can, and want to, learn the skill.

Though experimental, the Visotoner is emerging from the laboratory and classroom. After teaching the skill to several blind persons, we now can report preliminary results. The main requisite for success is that a candidate be keenly motivated to meet independently those reading needs for which high reading speeds are not usually important. Because use of context is important for efficient learning of the skill, previously acquired reading skill at the eighth-grade level using braille or print is very desirable.

The ability to learn to identify the tone patterns of letters and short words is essential. Apparently, some individuals lack this ability but little is known yet about its relationship to the use of the reading machine. Normal hearing is desirable but persons with subnormal stable hearing may also be able to use the machine.

We have found that students, after about 30 or 40 hours of practice, can learn to check material they have just typed. Additional practice is needed for reading typed correspondence, bank statements, labels, encyclopedias, etc. Besides reading skill, advanced uses require concept and knowledge of printed format; i.e., what to look for and where to look. One example of an advanced use is a housewife reading package directions and perhaps brailling them for easier, future reference.

Besides checking one's typing, other elementary uses include reading some meters and the large hand of a stop watch and detecting the presence and direction of many kinds of lights. Currency may be identified not by the numerals, but by the gross features, such as the columns on a $5 bill. The "sound of money" is pleasant indeed, and now "money can talk" to a vending stand operator.

With the Visotoner, blind typists may check their typing and correct any errors. I have taught the skill to Margaret Butow of the Hadley School for the Blind, 700 Elm Street, Winnetka, Illinois. She reads her typing and correspondence. The Hadley School is working on a short course to introduce the code of the Visotoner via tape recordings. The purpose is to determine a potential candidate's interest, ability to learn the skill, and likelihood to profit from the longer course of training. The Hadley course may be available by mid-1968.[a]

We feel that a blind person should first avail himself of the training given at rehabilitation centers or by home services. Then he may consider a machine like the Visotoner as a supplement to the basic skills.

I read with the Visotoner at speeds of from five to thirty words per minute, depending on the type of print, the paper, and the need for accurate reading. With this newly designed equipment, slightly higher rates of speed may be possible.

OTHER READING MACHINES

Under a research contract with the Veterans Administration, Mauch Laboratories is developing several reading machines for the blind. One of them uses eight tactile stimulators which are felt as vibrations by four fingertips of one hand. It is a sort of tactile optophone and is called the Visotactor.

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[a] Progress on the Hadley course is reported in the "Highlights of Other VA Research Programs" section of this issue.

We need small reading machines like those discussed for their low eventual cost (several hundred dollars including accessories) and for their high degree of versatility. For instance, they can be used to read italicized print, numerals and other symbols, and foreign languages.

Mauch Laboratories has built a prototype model of another machine it calls the Recognition Machine (2). The production model will be the size of an office typewriter. It now spells words audibly or it could be made with a braille output. A blind person, Miss Bonnie Reinicke, of Dayton, Ohio, now reads with the machine. It identifies upper- and lower-case letters in several common type fonts, so it permits more rapid reading at speeds of 90 or more words per minute. However, a Visotactor, similar to the one previously discussed, must be used as a part of the Recognition Machine to locate the print and size it up and keep exactly on the line. Only then will the Recognition Machine spell words. The small machine must also be used to read numerals and other symbols which the Recognition Machine cannot identify. The smaller reading machine will be detachable from the larger but faster recognition equipment for portable use in remote locations. In the event that several machines are fully developed, it may be possible to select the type of outputs used according to individual ability and preference.

WHAT ABOUT THE IMMEDIATE FUTURE?

The Visotoner and Visotactor are nearing the production stage. Because of small quantity production, the unit cost is currently too high for investment by individuals. Agencies may consider buying machines and training teachers and users. Reading machines would then be available to those trainees who had invested their time and effort in learning the skill.

The following is quoted from a July 1, 1967, Veterans Administration Information Sheet, only the cost figure being changed, a reduction from a $2,500 unit cost to the figure shown.

"Current plans for future development of the Visotoner and Visotactor systems . . . call for the production for expanded clinical trials of about 30 second-generation Visotoners and about 10 Visotactors Model B with associated Colineators, battery chargers and carrying cases. The unit cost in manufacturing runs of the order of 40–60 complete device packages is estimated at $1,850 at the present time. . . . There is a possibility that responsible agencies other than the development sponsor, the Veterans Administration, may wish to order one or more of these still-experimental devices for local trial purposes from the manufacturer, to be produced concurrently with the forthcoming Veterans Administration production run. . . .

"Those interested may request information from: Eugene F. Murphy, Ph. D., Chief, Research and Development Division, Prosthetic and Sensory Aids Service, 252 Seventh Avenue, New York, New York 10001."

I gratefully acknowledge the assistance of fellow team members on the staffs of the organizations referred to in this article.

Technology often makes old ideas feasible. Jet propulsion and magnetic recording were curiosities of the 19th century. Fifty years ago, Mary Jameson (3) of Great Britain demonstrated the first optophone at a speed of one word per minute. Today, she is still aiding in the evaluation of new equipment. Her example of foresight and dedication is still inspiring us.

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AN EVALUATION OF THE CROS-TYPE HEARING AID

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Until recently, there was little the clinical audiologist could offer in the way of help to the unilaterally impaired listener. Armed with the knowledge that one good ear is usually sufficient for most communicative needs, the audiologist often counselled that due to the limitations inherent to modern hearing aids and the unique problems of the one-eared listener, amplification would not be satisfactory. This type of individual frequently indicated that his hearing was adequate for face-to-face communication, but that he encountered considerable difficulty under some adverse circumstances. Harford and Dodds (1) cited three typically difficult situations encountered by the unilaterally impaired listener: First, when listening to speech originating from the side of the bad ear; second, when communicating in a noisy environment and; third, when attempting to locate the source of a sound. In the past, recommendations to this type of individual were generally restricted to suggesting that he modify his environment whenever possible to allow his good ear to be directed toward the sound source.

Within the last few years, Harford and his associates have proposed a method which allows the unilaterally impaired listener to benefit from amplification. The method, dubbed CROS (contralateral routing of signals), involves the location of the hearing-aid microphone on the side of the impaired ear with the receiver located at the side of the unimpaired ear. Thus, sounds directed to the poorer ear are amplified and routed across the head for hearing by the good ear. Harford and Barry (2) noted that the results of routine speech audiometry are often similar whether or not the CROS aid is worn. They stated:

> "Until more sensitive clinical tests are developed, the most meaningful approach to the final recommendation relative to CROS is its actual use by the patient. . . ."

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[a] Present address: Dept. of Audiology & Speech Science, Purdue University, Lafayette, Indiana.

The present study deals with efforts to develop procedures for evaluating CROS. Specifically, we were interested in determining whether the advantages and disadvantages, if any, of the CROS aid could be demonstrated in the laboratory.

Subjects for the investigation were twenty unilaterally impaired veterans selected on the basis of clinical audiograms. We required pure-tone threshold averages over the range from 500 to 2000 Hz to be better than 25 dB hearing level (HL) for the good ear, and poorer than 60 dB HL for the bad ear (International Standards Organization [ISO]–1964). Figure 1 shows the median pure-tone threshold levels for the better ears of the group in hearing level re ISO. Interquartile ranges for the losses at each test frequency are indicated by the striped lines about the median values.

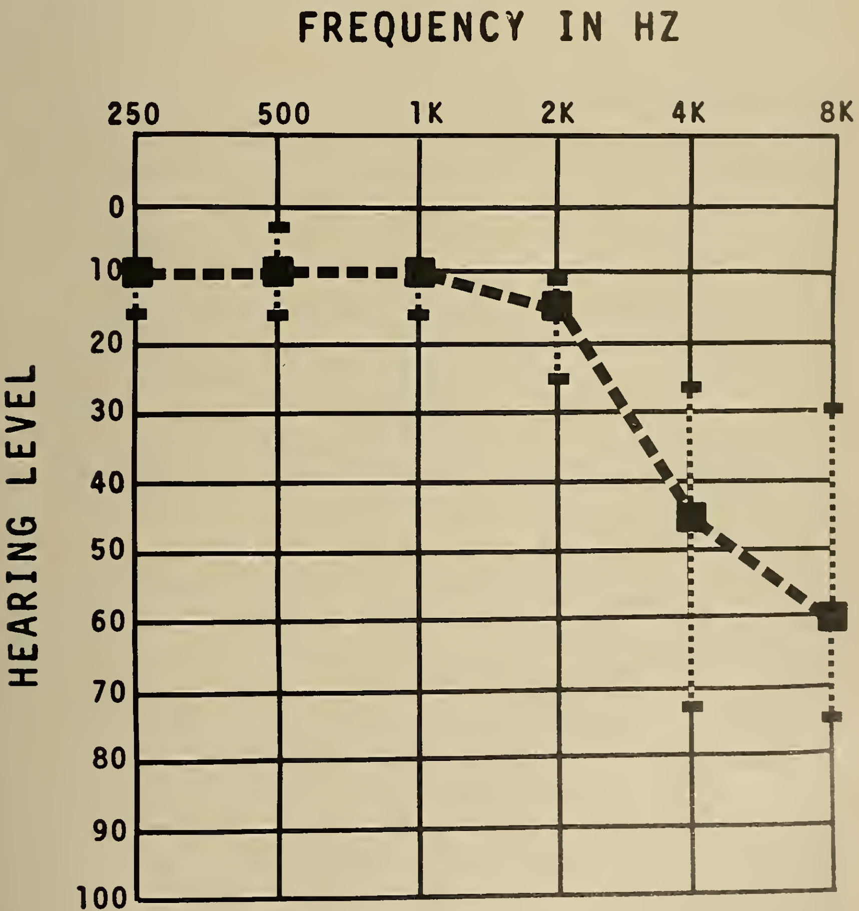
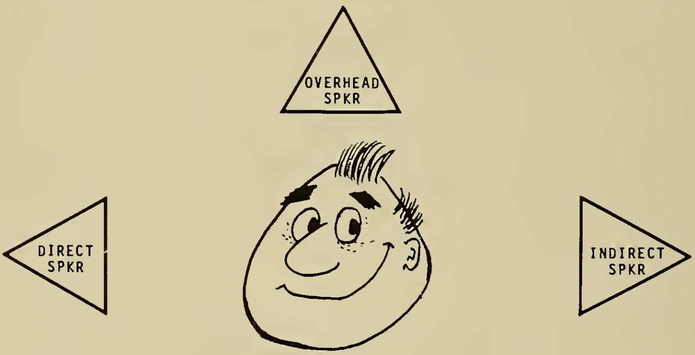


Figure 1.—Median pure-tone threshold levels (ISO–1964) and interquartile ranges for the better ears of the experimental subjects.

The revised Lehiste-Peterson Consonant-Nucleus-Consonant (CNC) word lists were used as the experimental stimuli. The CNC words were recorded on one track of magnetic tape with a competing signal, cafeteria noise, recorded on the second track. The taped materials were presented to the subjects via a dual channel tape recorder, through necessary amplifiers and attenuators, and finally to three loudspeakers. The loudspeakers and the subject were located in a sound treated room; the remainder of the equipment was located in an adjacent control room.

Figure 2 is a simplified display of the nature of the loudspeaker placement and description of the conditions which were achieved. The scale here, incidentally, is somewhat distorted. The subject was seated in the center of the test room directly between two loudspeakers and approximately four feet from each. The third loudspeaker was mounted directly over his head. The CNC words were presented from either of the two side speakers, but never from overhead; while the noise could be presented from any of the three speakers.

The conditions we employed are indicated at the bottom of Figure 2. They were specified on the basis of the relationship of the loudspeakers to the unimpaired ear. The direct loudspeaker was the one adjacent to the



CONDITION	STIMULUS		
	DIRECT LOUDSPEAKER	INDIRECT LOUDSPEAKER	OVERHEAD LOUDSPEAKER
SD--NI	Speech	Noise	---
SD--NO	Speech	---	Noise
SF--NO	Speech*	---	Noise
SI--NO	---	Speech	Noise
SI--ND	Noise	Speech	---

*Subject turned to face loudspeaker.

FIGURE 2.—Representation of loudspeaker placement and test conditions which were achieved. Direct speaker refers to loudspeaker located on the side adjacent to subject's better ear.

better ear and the indirect speaker was adjacent to the poorer ear. In the case of the figure, the right ear would be the good ear and the left the impaired ear. The conditions were: a. Speech Direct—Noise Indirect, b. Speech Direct—Noise Overhead, c. Speech Indirect—Noise Direct, d. Speech Indirect—Noise Overhead, and e. a fifth condition was achieved by turning the subject to face one loudspeaker. In that instance, the competition noise was presented by the overhead speaker.

Each subject was tested both unaided and aided under each of the five conditions with appropriate precautions to avoid systematic order effects. We employed two commercially available moderate gain CROS-type hearing aids coupled to the unimpaired ear by modified soft plastic inserts.

The CNC lists were presented at 70 dB sound pressure level (SPL) with a nominal signal-to-noise ratio of +8 dB. Both the presentation level and the signal-to-noise ratio were specified at the point in space to be occupied by the subject's head, but with the subject absent from the field. For the aided conditions the subject adjusted the gain of the CROS aid to a comfortable loudness in the presence of running discourse which was presented from the indirect loudspeaker, that is, from the speaker adjacent to the hearing-aid microphone and opposite the good ear.

The speech intelligibility scores obtained under the five unaided and five aided conditions were converted to deterioration scores relative to better ear discrimination in quiet. These results are displayed in Figure 3. On this graph the black bars represent the mean unaided performance for the group, and the white bars represent the mean aided performance. The height of each bar indicates the decrease in discrimination for that condition relative to discrimination in quiet under phones.

For two of the conditions, differences between unaided and aided performances were not statistically significant using the Wilcoxon matched-pairs signed-ranks test. On the speech direct—noise overhead condition and the speech from the front—noise overhead condition (simulating face-to-face communication) discrimination was about the same whether or not the hearing aid was employed, the decrease from discrimination under earphones being about 20 to 30 percent. This is consistent with the contention that routine audiometry might fail to distinguish between unaided and aided performance.

On the three remaining conditions, the differences between unaided and aided discrimination were more marked and were statistically significant beyond the .05 level using the Wilcoxon. For the speech indirect—noise overhead condition, we found a relative improvement of 15 percent through the use of CROS. Here, unaided scores deteriorated 37 percent re discrimination under phones while aided performance deteriorated only 22 percent.

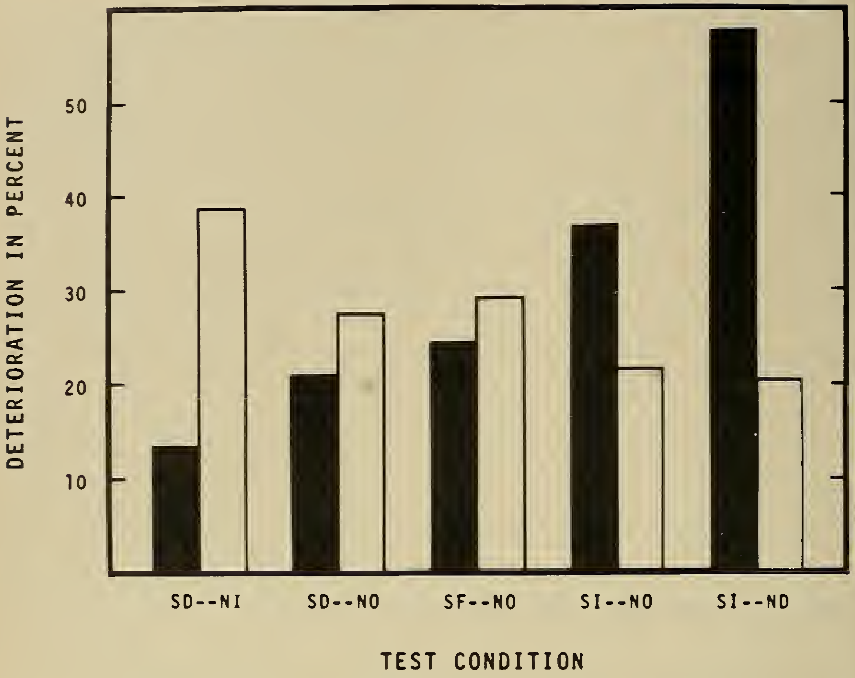


Figure 3.—Deterioration in intelligibility (reference discrimination in quiet) as a function of test conditon. Black bars represent mean unaided performance and white bars represent aided performance.

The speech indirect—noise direct condition and the speech direct—noise indirect condition tended to show the CROS aid at its best and its worst, respectively. In the speech indirect—noise direct condition, the unilaterally impaired subject found himself in the circumstances generally most difficult for him: namely, a noisy environment with speech coming to him from his bad side. Mean unaided performance in this situation decreased 58 percent from discrimination in quiet. Using the CROS aid resulted in a relative improvement of 38 percent.

Reversing this situation, that is, presenting speech from the side of the better ear and cafeteria noise from the side of the poorer ear, resulted in the relationship shown on the far left of the chart.

The unaided scores are better than under any other condition. This is not surprising, as the speech was delivered directly to the better ear while the effectiveness of the noise in masking that speech was reduced by the head shadow effect.

Wearing the hearing aid in this condition yielded a decrease in intelligibility of approximately 25 percent. Here, the aid served to amplify the masking noise which had been attenuated by the head baffle effect. Thus, under the most favorable condition for use, the aid provided a relative increase in performance of 38 percent and in the least favorable condition, a relative decrease of 25 percent.

The simple injunction to the user that he turn on his hearing aid in one situation and turn off his hearing aid in another appears to be a bit too simple. It is in just those circumstances such as meetings or group discussions in which the individual receives speech from a number of sources that he most requires the aid to attend to speech directed to his poorer ear. Similarly, it is in those same situations that the aid may be providing amplified masking when he desires to attend to speech emanating from his good side.

Although the CROS aid reduces the problems created by a unilateral loss on one side, it may under some circumstances create the effects of such a loss on the other side.

It should be mentioned that, almost without exception, the subjects in this study were highly enthused about the CROS aid after using it. This occurred despite the fact that performance with the aid was at times severely impaired.

It seems that the pair of conditions we labeled speech direct—noise indirect and speech indirect—noise direct (i.e., speech to the good side, noise to the bad; and speech to the bad side, noise to the good) may prove useful in further attempts to evaluate CROS-type hearing aids. The conditions are easily achieved and demonstrate both the advantages and disadvantages to be obtained from this type of amplification. It remains to be seen whether objective test scores such as these will prove satisfactory for determining the usefulness of CROS aids or in differentiating one CROS aid from another.

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PHYSICAL PERFORMANCE OF HEARING AIDS AS AFFECTED BY RECEIVER SUBSTITUTION

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INTRODUCTION

There are currently available several hearing aids which are provided with interchangeable receivers of different models for the purpose of altering the frequency response patterns of the instruments. The effect or change of electroacoustic characteristics of a given hearing aid resulting from a change of the frequency response has not been reported. Any such effect or change upon the nonlinear distortion characteristic which has been shown to influence listener intelligibility performance (Harris et al., 1961; Jerger, Speaks and Malmquist, 1966), or otherwise significant alteration of the hearing-aid performance in terms of gain or maximum power output is of direct concern to the audiologist for hearing-aid selection purposes.

Receiver substitutions may be made with a receiver of the same model which supposedly would not change the pattern of frequency response, or the substitution may be made by a receiver of a different model with the objective of altering the frequency response pattern of the hearing-aid output. The resulting substitution of receivers presents two important questions. First, does the replacement of a receiver of the same model as the one supplied with the hearing-aid transmitter provide the same electroacoustic performance characteristics of the hearing-aid output? This question is of particular interest with respect to hearing-aid repair which necessitates the replacement of a like receiver to make the instrument functional. For example, in a Veterans Administration pilot repair program of hearing aids at the Denver Prosthetics Distribution Center, of all the repairs accomplished during a 1-year period, 19.9 percent of these repairs included the replacement of receivers. The second question is, does the substitution of a different model receiver contribute to changes other than the frequency response pattern in the physical performance characteristics of a given hearing aid?

The purpose of this study was, therefore, to determine what changes in the physical performance characteristics of a hearing aid took place as a result of a change in the frequency response by the substitution of a different model of receiver, and to determine the reliability of performance characteristics of a hearing aid among different receivers of the same model.

METHOD

Electroacoustic performance characteristics were measured for a strong-powered body-type hearing aid. To provide different frequency response patterns of the hearing aid, four different models of universal receivers were used as well as the standard receiver recommended by the hearing-aid manufacturer. The impedance of the universal receivers was the same as the standard receiver. To determine the variability of hearing-aid performance with a given receiver model, five samples each of the standard and universal receiver models were evaluated.

Apparatus

Sine wave signals were generated by a beat-frequency oscillator (B & K Model 1014) and fed into a hearing-aid test box (B & K Model 4212) by means of a loud speaker. A constant input level to the test box was maintained by the monitoring condenser microphone, microphone amplifier (B & K Model 2603), and compressor circuit of the beat frequency oscillator. The output of the hearing aid placed inside the test box was fed to an amplifier (B & K Model 2603) and a distortion analyzer (Hewlett-Packard Model 330B) through a 2 cc coupler and calibrated pressure microphone. The output of the amplifier was coupled to a graphic level recorder (B & K Model 2305) for automatic recording of frequency response.

Procedure

The following measurements were made using the same hearing-aid transmitter for each of the five samples of the standard and four universal receivers:

Maximum Power Output (*MPO*). MPO was measured at 500, 750, 1000, 1500, and 2000 Hz with the volume control of the hearing aid set at the full-on position. The input level to obtain MPO was also noted.

Gain. With a 70-dB sound pressure level (SPL) input signal, the volume control was adjusted until the output of the hearing aid was 3 dB below saturation at 1000 Hz. Gain was recorded for the same frequencies listed above for MPO measurements.

Response versus frequency. An automatic recording was made of the gain versus frequency curve from 200 to 5000 Hz. These curves were recorded with a 70-dB SPL input signal with the gain control set 3 dB down from saturation at 1000 Hz.

Distortion. Total nonlinear distortion was obtained for the same input level and volume control setting as for the response curve and gain determinations. Measurements were made at the five frequencies of 500, 750, 1000, 1500, and 2000 Hz.

Signal-Noise Ratio. With the volume control and input level as in the preceding, the output of the hearing aid was recorded at 1000 Hz for comparison of the output SPL due to electrical self-noise in the absence of a signal.

RESULTS

Means and standard deviations were determined at each frequency tested for maximum power output, total nonlinear distortion, and gain of each model of hearing-aid receiver.

Examination of Table 1 shows the saturation levels for each of the receiver models to be fairly constant as a function of frequency. On the other hand, the mean MPO at each frequency for universal receivers #2 and #4 is approximately 5–10 dB lower than for the other receivers.

TABLE 1.—*Mean Maximum Power Outputs and Standard Deviations (in dB) of Standard and Universal Receivers*

Receiver			Hz				
			500	750	1000	1500	2000
Standard		M	130. 8	131. 4	131. 8	131. 4	130. 2
		SD	2. 0	1. 0	. 7	1. 4	. 4
Universal	#1	M	130. 0	129. 0	131. 0	134. 4	130. 6
		SD	2. 7	3. 1	3. 4	2. 4	2. 9
Universal	#2	M	126. 2	124. 4	125. 2	129. 4	125. 6
		SD	1. 0	7. 1	1. 8	1. 8	3. 1
Universal	#3	M	130. 6	132. 0	135. 2	132. 4	128. 0
		SD	1. 6	1. 0	1. 8	2. 3	. 6
Universal	#4	M	128. 0	126. 8	128. 8	133. 0	124. 8
		SD	. 6	1. 0	1. 1	1. 2	2. 9

Inspection of Table 2 indicates extremely low total nonlinear distortion found in this hearing-aid output regardless of the receiver used or the frequency considered.

Mean gain (relative to 1000 Hz) values are reported in Table 3. These values reflect the frequency response patterns of each receiver model. The general pattern of the universal receivers was a rising (high frequency emphasis) pattern somewhat sharper in slope to the standard receiver.

TABLE 2.—*Mean Total Nonlinear Distortion (in %) and Standard Deviations of Standard and Universal Receivers (the Input Signal was 70 dB SPL and the Volume Control of the Hearing Aid was Adjusted 3 dB Down from the Saturation Level at 1000 Hz)*

Receiver		Hz				
		500	750	1000	1500	2000
Standard	M	3.3	3.7	4.1	4.6	4.1
	SD	.5	0.0	2.0	1.8	1.7
Universal #1	M	4.3	4.1	4.0	4.9	2.1
	SD	3.7	1.8	2.8	2.7	.3
Universal #2	M	3.3	5.8	2.5	5.0	2.4
	SD	.7	2.3	1.3	3.1	.6
Universal #3	M	3.8	4.0	4.6	2.0	2.3
	SD	2.5	3.2	1.6	1.0	.7
Universal #4	M	2.5	3.5	2.3	4.0	2.3
	SD	.7	1.5	1.1	1.1	.3

TABLE 3.—*Mean Gain (in dB) Relative to the Gain at 1000 Hz and Standard Deviations of Standard and Universal Receivers*

Receiver		Hz			
		500	750	1500	2000
Standard	M	−8.0	−3.8	1.6	1.4
	SD	2.9	1.3	1.0	1.0
Universal #1	M	−7.0	−4.6	2.8	−2.2
	SD	4.1	2.3	5.0	3.0
Universal #2	M	−4.5	−3.0	7.0	−1.8
	SD	3.2	1.9	2.8	2.3
Universal #3	M	−8.6	−6.0	.2	−4.8
	SD	4.1	1.2	3.0	1.7
Universal #4	M	−5.2	−5.0	7.2	−.8
	SD	5.0	1.8	1.0	2.4

Performance Variability

To determine variability among the standard and universal receivers as well as the variability among the samples of each receiver model, analyses of variance were conducted for the four electroacoustic performance characteristics of maximum power output, nonlinear distortion, mean gain, and signal-noise ratio.

Maximum Power Output (*MPO*). Separate analyses of variance were conducted at each frequency tested (500, 750, 1000, 1500, and 2000 Hz). In each analysis the main effects were receiver models and model samples. The summaries of these analyses are reported in Table 4.

At three frequencies (500, 750, and 1000 Hz) significant differences in MPO were demonstrated among the receiver models. At 1500 and 2000 Hz, the F values were extremely close to the significance level. However, among the receivers of the same model, no differences approaching significance appeared at any frequency. From these analyses it is apparent the use of different models of receivers may produce different MPO's with the same hearing aid, particularly at lower frequencies with little likelihood of significant differences occurring among receivers of the same model.

TABLE 4.—*Summary of Analyses of Variance for Maximum Power Output*

Source	Sum of squares	df	Mean square	F
Models:				
500 Hz	77. 8	4	19. 4	[a] 4. 97
750 Hz	201. 9	4	50. 5	[a] 15. 78
1000 Hz	274. 8	4	68. 7	[a] 17. 17
1500 Hz	69. 8	4	17. 4	4. 70
2000 Hz	137. 4	4	34. 4	4. 69
Samples:				
500 Hz	15. 8	4	3. 9	1. 0
750 Hz	21. 1	4	5. 2	1. 6
1000 Hz	22. 8	4	5. 7	1. 4
1500 Hz	27. 6	4	6. 9	1. 7
2000 Hz	30. 2	4	7. 5	1. 0
Error:				
500 Hz	63. 0	16	3. 9	
750 Hz	52. 1	16	3. 2	
1000 Hz	64. 4	16	4. 0	
1500 Hz	59. 2	16	3. 7	
2000 Hz	117. 3	16	7. 3	
Total (all groups)	1235. 2	24		

[a] Significant at .01 level (4.77).

Nonlinear Distortion. As in the case of MPO, separate analyses of variance were conducted at each test frequency to determine variability of total nonlinear distortion among different receiver models and receivers of the same model. The summaries of the analyses are reported in Table 5. No statistically significant differences in total distortion appeared either among different models or among receivers of the same model. These results indicate that the substitution of a receiver, either of the same or different model, will not significantly change the amount of total nonlinear distortion at the output of a hearing aid.

TABLE 5.—*Summary of Analyses of Variance for Total Nonlinear Distortion*

Source	Sum of squares	df	Mean square	F
Models:				
500 Hz	6. 85	4	1. 71	. 54
750 Hz	15. 89	4	3. 97	. 73
1000 Hz	42. 20	4	10. 55	2. 29
1500 Hz	29. 93	4	7. 48	1. 22
2000 Hz	13. 96	4	3. 49	4. 41
Samples:				
500 Hz	12. 18	4	3. 04	. 95
750 Hz	20. 63	4	5. 13	. 94
1000 Hz	14. 44	4	3. 73	. 81
1500 Hz	19. 35	4	4. 83	. 79
2000 Hz	3. 24	4	. 81	1. 02
Error:				
500 Hz	50. 90	16	3. 18	
750 Hz	87. 09	16	5. 44	
1000 Hz	73. 56	16	4. 59	
1500 Hz	97. 53	16	6. 09	
2000 Hz	12. 64	16	. 79	
Total (all groups)	500. 39	24		

Mean Gain. The mean gain at 1000, 1500, and 2000 Hz was determined for the samples of receiver models. An analysis of variance was conducted using these means and is reported in Table 6. Neither the variance among the models nor the variance among the samples of the same model was significant. This would suggest, in the case of different models, that the frequency response pattern change due to the substitution of a receiver is not significant enough to influence the mean gain of the instrument in the mid-frequency range. The same is true if the mean gain of 750, 1000, and 1500 Hz is obtained and subjected to the same statistic (Table 7).

TABLE 6.—*Summary of Analysis of Variance of Mean Gain (1000, 1500, and 2000 Hz)*

Source	Sum of squares	df	Mean square	F
Models	142. 6	4	35. 6	2. 80
Samples	30. 5	4	7. 6	. 59
Error	204. 1	16	12. 7	
Total	337. 2	24		

TABLE 7.—*Summary of Analysis of Variance of Mean Gain (750, 1000, and 1500 Hz)*

Source	Sum of squares	df	Mean square	F
Models	130. 8	4	32. 7	4. 24
Samples	23. 2	4	5. 8	. 75
Error	123. 2	16	7. 7	
Total	277. 2	24		

Signal-Noise (S/N). An analysis of variance of S/N at 1000 Hz using receiver models and model samples as main effects was conducted. The summary (Table 8) shows no statistically significant differences for either receiver models or samples of the same model.

TABLE 8.—*Summary of Analysis of Variance of Signal-Noise Ratio at 1000 Hz*

Source	Sum of squares	df	Mean square	F
Models	194. 0	4	48. 5	1. 28
Samples	38. 0	4	9. 5	. 25
Error	606. 0	16	37. 8	
Total	838. 0	24		

DISCUSSION

Aside from the fact that the frequency response patterns of a hearing aid may be changed by the substitution of a different model receiver, significant changes of other electroacoustic characteristics as measured in this study do not occur except with regard to MPO at the lower frequencies. Even though these differences in MPO occur statistically, it is questionable whether these differences are clinically significant while the other physical performance characteristics remain constant.

The lack of physical performance differences occurring with the use of different receivers on the same hearing aid again presents the proposition, which has been supported by Shore, Bilger, and Hirsh (1960) and Harris et al. (1961), that little or no influence on listener intelligibility occurs resulting in a change of the frequency response pattern of a hearing aid. That is, a frequency response pattern which is suppressed at one end of the frequency spectrum by the substitution of a receiver, will not either enhance or degrade the fidelity or change other electroacoustic charactistics of the instrument enough to improve or reduce speech intelligibility. This being the case, the clinical concern should be whether such a substitution of a receiver will provide an instrument which "sounds better" or "sounds worse" to the user, rather than will such a substitution provide more or less intelligible speech with a given hearing aid. The clinical concern thus becomes a quality judgment on the part of the listener following the selection of the aid by the audiologist according to his criterion. It therefore appears that the use of universal receivers can be made without contributing significant effects upon the physical performance characteristics of the hearing aid other than the frequency response pattern, and this change of pattern is in effect probably influential only as a tone control.

The absence of variability among receivers of the same model indicates a relatively good quality control in the manufacture of receivers. Clinically, this is of importance when it is necessary to replace an existing receiver because of damage or inoperative condition. Such a change can therefore be accomplished without influencing the user's intelligibility performance or necessary usable gain expected with his hearing aid.

SUMMARY

Physical performance characteristics of a hearing aid were measured using five samples of a standard receiver and five samples each of four different models of universal receivers. The only significant statistical differences found among different models of receivers was for MPO at the lower frequencies. Statistical differences among receivers of the same model were not found at any frequency for any electroacoustic characteristic measured.

The results indicate that the substitution of hearing-aid receivers (matched to the impedance of the output of the hearing aid) do not alter physical performance characteristics other than frequency response, and therefore should not affect listener intelligibility performance.

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HEARING-AID EVALUATION: AN EXAMINATION OF TWO PROCEDURES

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Carhart (1950) stated that the problem of hearing-aid selection was currently the most controversial aspect of clinical audiology. Seventeen years later, according to an ASHA Report of A Conference on Hearing Aid Evaluation Procedures (1967), hearing-aid selection is still one of the most controversial aspects of clinical audiology.

There is a wide variety of opinion concerning the need for formal hearing-aid evaluations as described by Carhart (1946). In the selection of an aid to provide maximum benefit for the hearing-impaired individual, some audiologists feel that any hearing aid meeting certain specifications will satisfactorily benefit the patient. Others are of the opinion that variations in performance may be important to the individual and that each hearing aid must be evaluated under standardized or similar conditions to predict which hearing aid will be the most beneficial.

The present study was conducted to determine if a hearing aid chosen on the basis of a formal type of hearing-aid evaluation would perform more satisfactorily after a period of use than one arbitrarily selected.

PROCEDURES

The subjects consisted of 24 hearing-impaired veterans who were patients of the Audiology and Speech Pathology Service, VA Hospital, Washington, D.C. The average pure-tone loss for the better ear of the subjects was 50 dB International Standards Organization (ISO) or poorer. Three types of hearing impairment, predominantly conductive, predominantly sensorineural, and mixed, were represented about equally among the subjects. All of the subjects had worn hearing aids for a minimum of 10 years. They were randomly divided into two equal groups, Groups A and B, to counterbalance the order of the experimental conditions.

The audiometric equipment was located in an IAC sound suite, Model 1205 ACT. The instrumentation included a Grason-Stadler Speech Audiometer, Model 162; a Magnecord Tape Recorder, Model 748, and an Electro-voice SP 12 speaker in an Electro-voice Aristocrat enclosure.

The stimulus materials were the revised Consonant-Nucleus-Consonant (CNC) Monosyllabic Word Lists (Lehiste & Peterson, 1962) recorded by a male speaker considered to have general American speech. The tapes of each list included a 1000 Hz calibration tone recorded at the long term r.m.s. level of the speech signal. The lists were presented both in quiet and noise. A recording of cafeteria noise was used as a masking source for the noise task. This noise was chosen because of its broad band and transient characteristics.

One hearing-aid model from each of four manufacturers was selected for the study. These particular models were among those in the VA stock for Fiscal Year 1967. They were of the body type and in the strong power category. Each aid was adjusted according to manufacturers' specifications to yield a broad, full-range frequency response.

A Bruel and Kjaer test system was utilized to obtain a gain versus frequency response curve, harmonic distortion measurements, and signal-to-noise ratio for each hearing aid. All measurements were obtained with the volume control set to yield 6 dB less than maximum gain at 1000 Hz. Instruments which did not conform generally to the mean performance pattern of their particular model were not utilized in the study. The means reported in Table 1 indicate that the average performance of the aids utilized represented satisfactory physical characteristics. It was our purpose to have four well-performing instruments in each hearing-aid evaluation.

The initial testing procedure for each subject required that a formal hearing-aid evaluation be performed with four instruments representing the four different hearing-aid models. The order for testing the aids was systematically varied among the subjects. Each subject was seated in the examination room, and the experimenter mounted the first test aid on a baffle located on a horizontal plane with, and facing, the loud speaker.

TABLE 1.—*Mean Gain, Signal/Noise Ratio, and Harmonic Distortion for Each Hearing-Aid Model* [a]

Model	Mean gain in dB	Mean S/N ratio in dB	Mean harmonic distortion (percent)
I	53	55	5. 9
II	61	51	6. 2
III	53	60	5. 4
IV	49	61	4. 9

[a] All measurements were obtained at a volume control setting 6 dB down from maximum gain at 1000 Hz.

While the volume setting of the aid under test was being adjusted to a comfort setting by the experimenter, running discourse was presented through the speaker at 70 dB sound pressure level (SPL). When a comfortable level for listening was indicated by the subject, this volume setting was used for all tests with that instrument. The same procedure was followed for all four aids.

Measurements of aided speech discrimination were obtained first in quiet and then in noise using a different CNC list for each test. The discrimination materials were presented at 70 dB SPL measured at the face of the hearing aid. A signal-to-noise ratio of +10 dB was used for the test in noise.

After administration of the tests in quiet and in noise with each aid, the results were weighted in order to emphasize the more difficult task. The discrimination test in quiet was given a value of one, and the discrimination test in noise was given a value of two. These two resultant figures were then summed and averaged. The aid with the highest score was labeled the clinically chosen aid. An aid from among the remaining three of the four tested was identified as the arbitrarily selected aid by means of a restricted Latin Square technique. Both the clinically chosen and the arbitrarily selected aids were worn during successive 1-month trial periods. The subjects in Group A wore the clinically chosen aid during the first month and the arbitrarily selected aid during the second month. The trial conditions were reversed for the Group B subjects. In order to avoid the effects resulting from changes in hearing-aid performance, the aids assigned to a subject were used exclusively by that subject throughout the remainder of the experiment. A total of 71 hearing aids was required to complete the study.

Upon completion of the 1-month trial period, each subject returned to the clinic and was retested with the aid used during that time. Thereupon he was loaned the other aid which had been set aside for him for the second 1-month trial period. After this trial period, discrimination scores were obtained with the second aid. In like manner, discrimination scores were again obtained with that aid. After each trial period, the subjects completed a questionnaire regarding quality judgments of the aid.

The primary purpose of the questionnaire was to force the individual to rate the performance of each aid in a uniform and thorough manner.

RESULTS

Discrimination scores obtained for the quiet and noise tasks as well as the weighted scores were tabulated for both the arbitrarily selected and clinically chosen aids. These results, further identified by initial and retest conditions, are reported in Figure 1. For the initial test the difference between the clinically chosen and arbitrarily selected aids in quiet was 7 percent, in noise 9 percent, and the weighted score difference was 8 percent. These differences were significant at the .05 level. By definition of course, the scores obtained during the initial test condition for the arbitrarily selected aid would be lower than the scores for the clinically chosen aid, since the clinically chosen aid was always the one performing best in the initial evaluation.

The differences in discrimination scores between the two aids on the initial test were not present after a 1-month trial period. Upon retest, the difference in discrimination scores between the clinically chosen and arbitrarily selected aids in quiet was 1 percent, in noise 1 percent, and the weighted score difference was also 1 percent.

An analysis of the changes in discrimination scores effected by the 1-month trial period with each aid was conducted. Each subject's improvement or decrement upon retest was tabulated, and the summary appears in Figure 2. Upon retest, nine subjects showed mean improvement of 6 percent with the clinically chosen aid. Also with that aid, 15 subjects got mean scores 7 percent lower than on the initial test. With the arbitrarily selected aid, 15 subjects showed mean improvement of 13 percent upon retest. Mean retest scores 5 percent lower than on the initial test were obtained by seven subjects with that aid.

At the end of the second trial period, each subject was asked which of

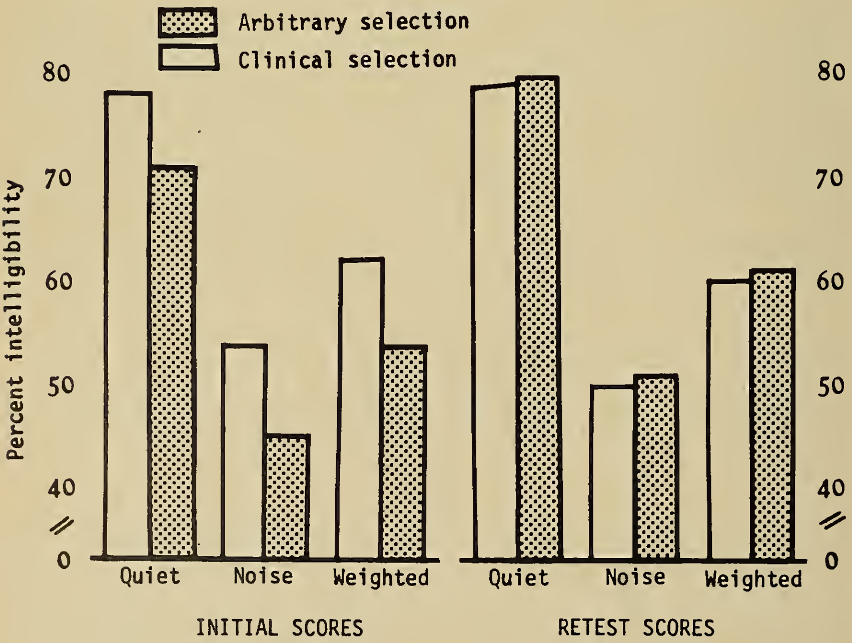

Figure 1.—Mean intelligibility scores.

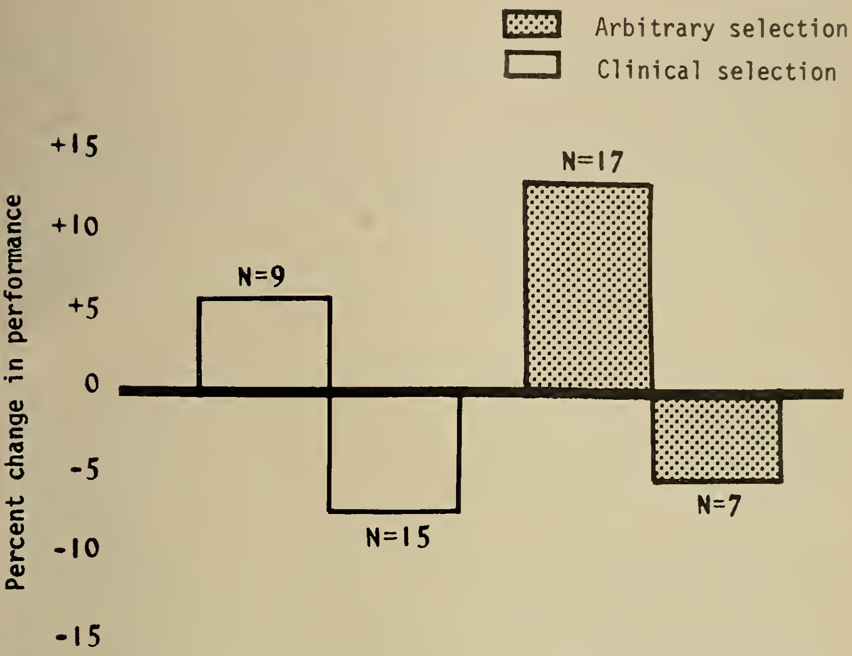

FIGURE 2.—Effect of trial period on weighted discrimination scores.

the two aids he tried seemed more beneficial. The clinically chosen aid was preferred by nine of the 24 subjects. Six individuals in this group had achieved their highest weighted discrimination scores with the aid they preferred. The arbitrarily selected aid was preferred by the remaining 15 subjects. Nine of these individuals had achieved their highest weighted discrimination score with the aid they preferred. The Chi Square Technique demonstrated no significant difference between the two alternative choices made by the user.

DISCUSSION

It should be emphasized that the hearing aids used in this study met VA criteria for acceptance on contract (Johnson and Causey, 1956; Davis and Silverman, 1965). Their electroacoustic characteristics were quite similar so test materials which would reveal subtle differences were needed. The CNC Revised Word Lists, heavily weighted with the noise condition, were effected to produce a more exacting and discriminating task.

Initial mean weighted discrimination scores did reveal significant performance differences among the hearing aids. This lends encouragement to those who feel that the hearing aid evaluation is a worthwhile procedure. The significant mean discrimination score differences which existed between the clinically chosen and arbitrarily selected hearing aids prior to a trial period no longer were apparent after the trial period. This finding supports the feeling of Glorig (1966) that performance with a new hearing aid will improve if sufficient time is spent in learning the new encoding system. Since the mean scores of the clinically chosen and arbitrarily selected hearing aids were extremely similar upon retest, it was not surprising that there be approximately equal preference for these aids among the subjects.

While a host of inferences might be ventured from these data, it is recognized that further investigation is needed utilizing hearing aids with a wide variation in electroacoustic performance, rather than high homogeneity as in this case.

SUMMARY

Twenty-four subjects received a formal hearing-aid evaluation utilizing four different strong power hearing aids having extremely similar electroacoustic characteristics. Two of these aids, one clinically chosen and one arbitrarily selected, were loaned to each subject for two separate 1-month trial periods. After each trial period, the subjects' performance with the aid on loan was again formally evaluated. Upon completion of the second trial, the subjects were asked which of the two aids seemed more beneficial.

Analysis of performance for initial tests revealed significant performance differences among the four hearing aids. These significant performance differences were no longer apparent in the retest scores after the trial periods. The number of subjects preferring the clinically chosen aid rather than the arbitrarily selected aid was not significant.

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VETERANS ADMINISTRATION PROSTHETICS CENTER RESEARCH

INTRODUCTION

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A spectrum of prosthetics and orthotics research activities is treated in this tissue. Noted is the continuation of the work discussed in the previous report, particularly on evaluations of powered artificial hands and on classification of lower-extremity hardware.

Several of the powered hands discussed previously were not then available to us. We have since obtained the later version of the Beograd hand which is discussed in this report. Eventually we should like to test all in a like manner, primarily using laboratory measurements but also including limited patient fittings.

Similarly, the report on the orthotics hardware being used by the VA shops follows the work reported in the last issue on functional classifications for such items. This is another step in accumulating information needed in establishing a sensible nomenclature for orthotics.

The upper-extremity control system discussed in this issue can soon produce the strategic introduction of powered elements into otherwise standard artificial arms. Unilateral above-elbow and shoulder-level amputees can benefit significantly from the reasonably simple addition of externally powered elbow flexion and extension, with other functions, especially terminal device operation, remaining directly linked to body (biomechanical) power and control sources. This simple control system makes this first step in "hybridization" clinically feasible; moreover, a significant number of (unilateral) amputees can benefit. We will therefore put emphasis on this item so that as soon as possible a good electrically powered elbow and a control mechanism like the one described in this issue will be available to our VA clinics for testing and eventually to the market. In the meantime, increased levels of hybridization will be undertaken; probably the control problem of rotation around the long axis of the forearm will be considered next.

Another major theme of this issue is covered in the work reported on the employment of pressure transducers in prosthetics and orthotics. It has seemed to us that an excessive program effort has gone into the development of pressure or force transducers with attempts being made to achieve a degree of perfection that is perhaps not indicated. It is now timely to use the instrumentation available and get down to the business of studying the prosthetics and orthotics problems requiring such instrumentation.

New York University under a VA research contract has, unlike any group in this country, made some measurements on the stump-socket interface even though they used bulky gages which required the cutting of openings in the socket wall. Nevertheless, their laboratory studies are the only ones that have been done on the problem. It seems now that with the use of the smaller transducer mentioned in this report, New York University can proceed with socket studies without the major socket wall alterations and thus with more flexibility in locating gages. We propose to assist them in this work.

Simultaneously the same type of pressure transducer can be employed in studies of the shoe-foot interface probably in conjunction with the barograph which gives the pattern of pressure on the shoe-floor and foot-floor interfaces. We believe that we can now begin to obtain information about this very critical problem in orthotics. It is therefore anticipated that orthopedic shoes and shoe modifications will be studied using these instruments in attempts to develop a rationale for the prescription and use of different orthopedic configurations around the foot. To us in the Veterans Administration, the shoe is a major problem. We have a great number of veteran beneficiaries requiring either arch supports, shoe modifications, custom-formed innersoles, or complete orthopedic shoes. The VAPC alone is responsible for thousands of such cases. Therefore it is logical for us to spend some time and money in research on the principles underlying designs of this type of appliance. Fortunately for this project we will have available the consultation of Dr. Herbert Elftman of Columbia University.

Pressure measurements on patients using elastic hose are also significant. We have repeatedly questioned the design of these items, particularly their effectiveness in providing the kind of pressure gradients for effective venous return. Studies of the pressures applied to the lower extremity using the type of transducers discussed in this report should be followed eventually with the introduction of a pressure gage which can be used in the clinic to check the effectiveness of an appliance in providing the necessary pressure pattern. Hopefully such a pressure gage could be used for other purposes, at the foot-shoe interface and in limb and brace sockets.

The same VAPC-Sensotec pressure transducer will also be employed in telling us more about the parameters in immediate fitting of prostheses. We should, for example, like to know more about the pressures applied between rigid dressing and stump. At the same time we should like to record other data about temperature and muscle activity. But important is the fact that this type of pressure transducer will now permit us, with the cooperation of one or more VA projects such as the one in Seattle, to learn more about the nature of the rigid-dressing interface in the immediate fitting regimen.

This is but a first step, for more needs to be learned about immediate fitting especially including studies of other biomechanical and physiological variables. For example, election of levels of amputation in ischemic cases appears to be a function of the type of surgery and the mode of rehabilitation such as immediate fitting. How do in fact the surgical technique and the prosthetic activities soon after amputation affect healing with lower and lower amputation levels? And it is important not only to know how but to estimate why.

I. LOWER-EXTREMITY PROSTHETICS
  A. Basic Studies
    1. Compression of the Lower Extremity
    2. Gait Patterns of the Aged
  B. Development (Components)
    1. Adjustable Below-Knee Standard Prosthesis
    2. Adjustable Standard Above-Knee (Multiplex) Prosthesis
  C. Development (Techniques)
    Direct Forming of Below-Knee Sockets
  D. Evaluation (Components)
    Revised UC–BL Pneumatic Above-Knee Swing Control Mechanism
  E. Evaluation (Techniques)
    None
II. UPPER-EXTREMITY PROSTHETICS
  A. Development
    VAPC Upper-Extremity Control System
  B. Evaluation (Components)
    1. AIPR (American Institute of Prosthetic Research) Externally Powered System
    2. Evaluation of Externally Powered Hands
    3. Fillauer Low Friction Transmission System
    4. Humeral Rotator
  C. Evaluation (Techniques)
    Direct Forming of Below-Elbow Sockets
III. LOWER-EXTREMITY ORTHOTICS
  A. Development
    1. Survey of Brace Components
    2. Arch Supports
  B. Evaluation (Components)
    1. VAPC Modular Single-Bar Brace
    2. AMBRL Fiberglas-Epoxy Drop-Foot Brace
  C. Evaluation (Techniques)
    Measurement of Foot Parameters

IV. ORTHOPEDIC AIDS
  A. Development
    None
  B. Evaluation (Components)
    1. Home Stairway Lift
    2. Revised Model Power Aid
    3. Wheelchair Pads
    4. Howmet Wheelchair
  C. Evaluation (Techniques)
    None
V. TESTING
  A. Standards Development Program
    1. Elastic Hosiery
    2. Comparative Analysis of Eight Wheelchairs
  B. Compliance Testing
    1. Stump Socks
    2. Upper-Extremity Components
    3. SACH Feet
VI. OPERATIONS REPORT FOR FIRST HALF, FISCAL YEAR 1968
  A. The Orthopedic Shoe Service
  B. The Prosthetics-Orthotics Service
  C. The Restorations Service
  D. Special Clinic Team

REPORT

I. LOWER-EXTREMITY PROSTHETICS

A. Basic Studies

1. Compression of the Lower Extremity. In continuation of our efforts to develop adequate methods for measuring pressures applied to the lower limb by elastic hosiery and other orthopedic devices, we have employed two new methods. Both the "Komprit," a pneumatic pressure gage of German manufacture, and an electronic pressure transducer have been used to measure pressures applied by elastic hosiery to the lower leg. The results of these studies are reported in Section V.A.1. Of special interest, however, is the electronic pressure transducer and its potential value in other studies of pressure applied by orthotic and prosthetic devices.

The basic transducer consists of a metal capsule 0.5 mm. thick and 6.35 mm. in diameter. One face is a diaphragm incorporating a full wave, temperature-compensated, semiconductor strain gage bridge. The output is 20 millivolts at full scale pressure, with ±0.5 percent full scale linearity and hysteresis. The gage is compensated for temperature at .05 percent full scale per degree Fahrenheit. The basic Sensotec transducer manufactured by Scientific Advances, Inc., of Columbus, Ohio, was modified according to our specifications. The original gage was inadequate for other than purely hydrostatic conditions. The entire unit (Fig. 1) is now encapsulated in a silastic rubber droplet giving it a concave surface on one side that provides intimate contact with the skin. With its modified radius of curvature due to the silastic coating, linear and repeatable results were obtained. A calibration curve (Fig. 2) for the unit was obtained with the pressure being applied through a simulated "skin." In this test the inactive side of the gage was placed against a rigid backing (as it is when used in a socket), and the active side of the gage was covered with a sheet of Sylgard 51 that was exposed to controlled pneumatic pressures.

Additional tests using Polysar as the socket material, showed the gage to be reliable in measuring the interface pressure between the skin and the socket. In Figure 3 are the results of interface pressure measurements when outside pressure is applied to the Polysar by a pneumatic sleeve.

The development of a small, thin, reliable pressure transducer is a significant event in prosthetics. For many years the need for such a device has frequently been expressed at meetings of the National Academy of Sciences—National Research Council, Committee on Prosthetics Research and Development. Several universities and other agencies have been granted prosthetics research funds for the development of such a pressure transducer.

During the past 5 years many attempts have been made to solve the difficult problems of accurately and reliably measuring pressures at the interface between stumps and sockets. Among all the laboratories engaged in this work, only the group at New York University under the direction

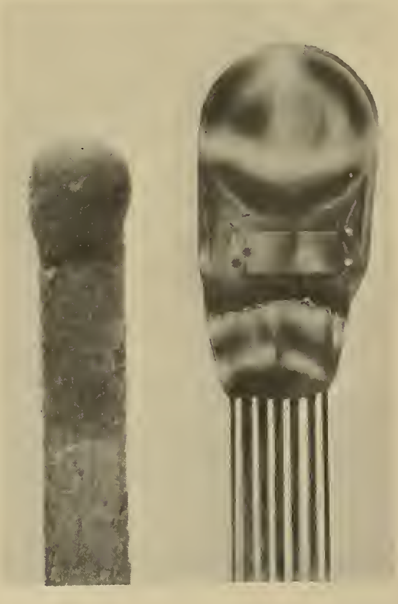


FIGURE 1.—VAPC-Sensotec semiconductor strain gage pressure transducer shown beside paper match.

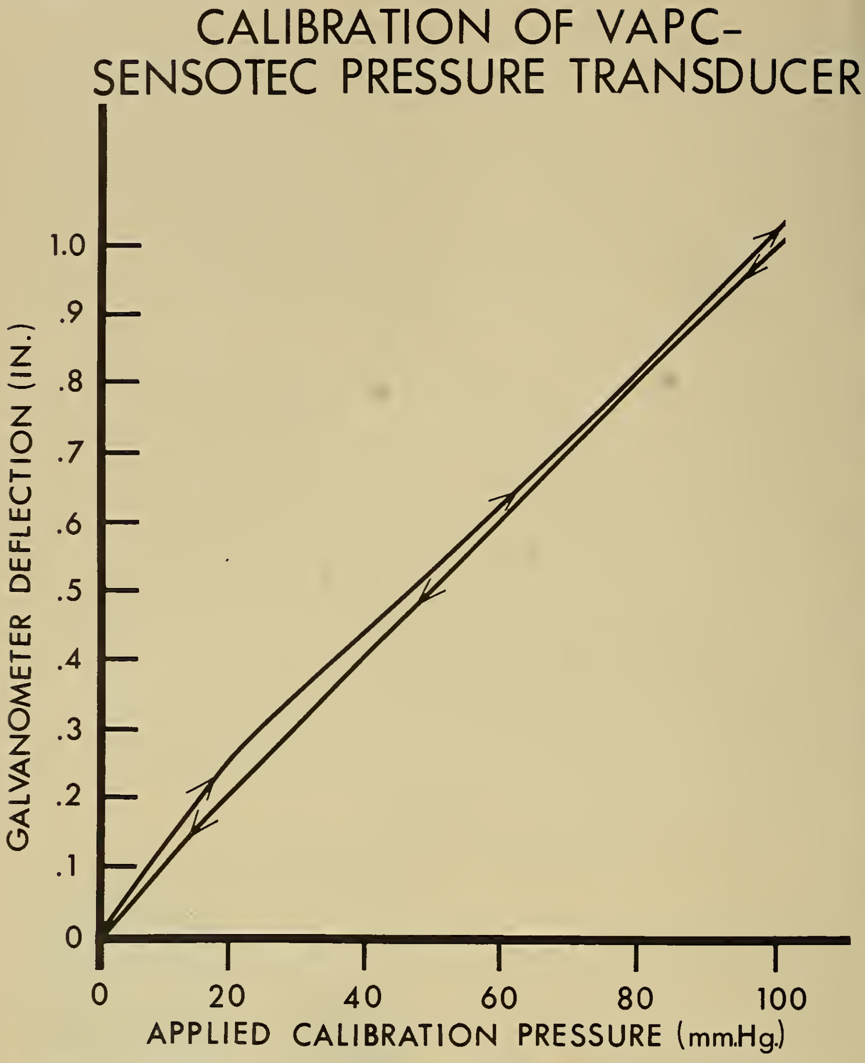


Figure 2.—Calibration curve of VAPC-Sensotec pressure transducer shows that response is linear. Hysteresis is negligible as indicated by similarity in the loading and unloading curves.

of Mr. Renato Contini has actually measured stump/socket pressures and correlated these pressure patterns with gait events. The success of the New York University group is a breakthrough of great magnitude. It has placed within our hands the means for studying and evaluating socket design and fit, perhaps the most crucial element in prosthetics service and one which had defied objective analysis to date. Credit for this breakthrough and for the scientific excellence of their work in measuring pressure with great

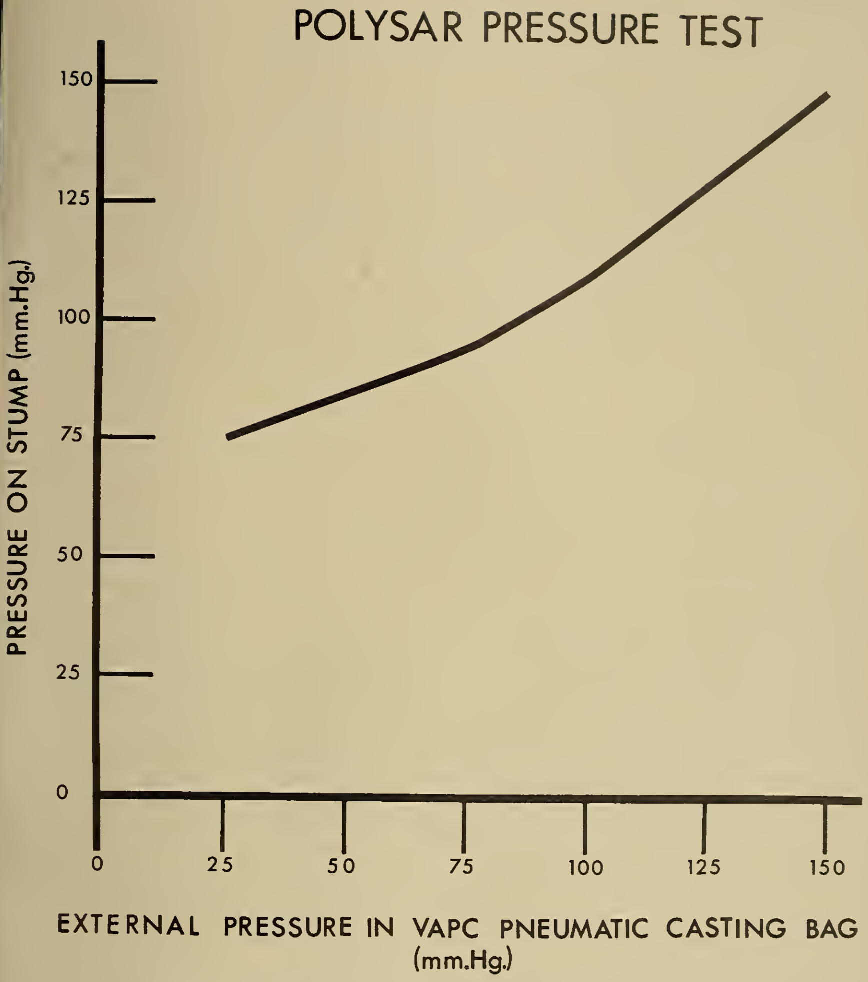


FIGURE 3.—VAPC-Sensotec transducer indicates that pressures applied externally to Polysar casts produce less-than-proportionate increments on the stump, up to approximately 90 mm. Hg. Higher external pressures produce equal internal increments.

precision and reliability belongs to NYU. Their pioneering work established the basic criteria for the study of pressure and only they have measured the pressures at such critical points in the socket as the lateral wall, the ischial seat, and the distal end. Their studies employed extremely accurate and reliable pressure gages, but due to their large size, they were inserted through the wall of the socket. They could not be applied to all sockets on a clinical basis without destroying the socket structure. Based on their work, we have redesigned a commercially available pressure transducer for use as a clinical evaluation tool. Due to its small size, durability, and reliability, the VAPC-modified Sensotec pressure transducer is now being used in several studies.

Currently underway in cooperation with the Prosthetics Research Study in Seattle is a program to study pressures applied by rigid dressings in the immediate postsurgical fitting procedure. The amputation management procedures suggested by Dr. Marian Weiss of Poland have been studied and elaborated during the past several years in Seattle by Dr. Ernest M. Burgess under VA sponsorship. During this period over 120 patients have been the subjects of the recommended myoplastic and myodetic surgical procedure, the application of a rigid plaster-of-paris dressing, and early weight-bearing and ambulation. At the Seattle project these procedures have yielded highly beneficial results. Pain and edema are reduced to the vanishing point, stumps are firm and clean, hospital time is reduced, and problems associated with fitting of permanent prostheses are minimized. According to Dr. Burgess, these results depend on the triad of fundamental procedures employed in the amputee management program: myoplasty, rigid dressing, early ambulation. Myoplasty and myodesis are assumed to be the causal factors in producing stumps with good muscle tone since the traumatized muscles continue to perform in a physiological manner. The rigid dressing is assumed to be the causal factor in preventing edema and possibly pain, by reason of the mechanical restriction of excessive fluid collection and subsequent swelling of the tissue. Early weight bearing and ambulation are assumed to reestablish or increase pressures between the dressing and the stump and enhance normal healing. The general circulatory changes associated with change of posture or activity of the traumatized muscles during early ambulation may also have beneficial effects on healing.

This basic management program has been standardized by the Seattle team to the extent that it is being taught to teams from the Veterans Administration and other institutions. In transferring the knowledge and experience of the Seattle team to others, it is difficult to specify the appropriate pressure to be applied by the rigid dressing. The Seattle group plans to measure pressures between the stump and the socket to determine the pressure magnitudes normally applied by the rigid dressing and to monitor pressure vicissitudes until the cast is removed. These data on pressure therefore will serve as a guide in the initial application of the rigid dressing and in subsequent reapplications. The utility of these data may depend on the capability of controlling pressures while applying the dressing, a difficult problem with plaster-of-paris. The use of Polysar and the pneumatic casting techniques (BPR 10–3) designed to control pressure may overcome the difficulty.

In addition the Seattle group plans to obtain objective measures of other effects of these procedures. The EMG activity of the stump musculature will also be studied as an indication of its "tone" or physiological condition.

The electrical activity of the gastrocnemius and the tibialis anterior muscles will be monitored before and after amputation. Temperature will be measured in an effort to chart the course of the inflammatory response to trauma.

At the VA Prosthetics Center we are also using the pressure transducer in studies of the biomechanics of socket design. The UC–BL quadrilateral socket design calls for shaping the socket to maintain the stump adducted and flexed to prevent lateral instability of the hip in stance phase and to optimize the extension capability of the hip in early stance phase. The ischial seat and the critical anterior-posterior socket dimension are designed to distribute body weight between the ischium and the proximal portion of the thigh. Total contact designs are intended to distribute the body weight somewhat differently. We are now studying above-knee socket pressure patterns with the VAPC-Sensotec pressure transducer in an effort to validate the biomechanical theory underlying the UC–BL quadrilateral and the UC–BL patellar-tendon-bearing socket as originally expressed by Professor Charles Radcliffe of the University of California at Berkeley (1). In addition we are attempting to develop a clinically useful system employing pressure gages to evaluate socket fit.

2. *Gait Patterns of the Aged.* With the increasing age of World War II veterans and the increasingly older groups coming to the attention of civilian agencies, a great deal of interest has been generated about the special considerations which may be required in the prosthetic and orthotic fitting of the so-called geriatric patient. At the present time, prosthetics and orthotics services for these patients consist of modifying conventional systems to make them lighter, reduce the effort required to use them, and to stabilize patients to prevent falls. In essence, components designed for the young or middle aged, relatively vigorous amputee and paralytic, are modified to serve the aged. The underlying assumption, obviously, is that the aged, but otherwise normal person, walks in a fashion similar to younger persons—perhaps more slowly but nevertheless with similar temporal, kinematic, and kinetic characteristics. A corollary asumption is that the aged amputee can or does walk in a manner similar to the younger amputee. The tenability of these assumptions seems questionable in the light of several bits of evidence.

According to Drillis (2), cadence, step length, and speed of walking generally decline among the *non-amputee* aged population beginning at approximately 45 years. Moreover, his data indicate that the variability of these factors is also smaller than in the normal population. In general, average cadence declines approximately 10 percent in the 60–70 year old group and the range of speed is halved. Average step length in this age category is reduced approximately 20 percent and the range is reduced by approximately 30 percent. Average speed of walking is reduced by approximately 20 percent and the range of speed is reduced by 30 percent. Bearing in mind that these data described a *normal non-amputee* population (approximately 750 subjects), we can expect that the performance of the *geriatric amputee* population will be even further modified.

A hypothetical but realistic geriatric above-knee amputee 60–70 years of age might be expected to walk at a cadence between 60 and 70 steps per minute, with a step length of approximately 25–28 in. and at a velocity of 2.0 to 2.5 m.p.h. Furthermore, increasingly reliable clinical observations indicate that aged (non-amputee) persons walk with a flat-footed gait, i.e., they do not exhibit the "normal" heel-toe transition. They also tend to walk over a flexed knee in stance phase without exhibiting the normal knee flexion in early stance phase followed by extension and subsequent knee flexion prior to toe-off. These and other observations lead us to believe that the normal locomotion pattern of the aged but otherwise normal population is significantly different from the normal pattern for younger people. Identifying and quantifying the gait factors which distinguish the aged from the younger population may be extremely valuable in providing guidelines for the design and development of special prosthetic and orthotic components for older disabled people.

With this in mind we have undertaken a study of the locomotion patterns of the aged. This study is being carried out in cooperation with Dr. H. Lippman of the Albert Einstein Hospital and Dr. Morris Brand of the Sidney Hillman Health Center, New York City, both of whom have had long experience with "geriatric" patients. We have deliberately tried to avoid the term geriatric since in current usage it has become so inclusive as to defy operational definition. As presently used, the term geriatric conjures up a patient perhaps over 65 years of age with a syndrome of infirmities which may include poor hearing, deficient sight, balance problems, arthritis, and other disease processes. To simplify the approach to this problem we are selecting subjects above 65 years of age who are otherwise unimpaired beyond the normal diminution of physical capacity and who are not under treatment for significant diseases.

The research program is designed to follow the general pattern of the earlier studies at UC–BL which produced the current standard reference data on normal human locomotion. Because instrumentation development has advanced since those studies were completed, additional data are being collected. The principal outcomes of this study will be a quantitative description of the temporal, kinematic, and kinetic factors in the gait of older people and an analysis of the significance of the differences between their gait and those of the younger population.

B. Development (Components)

1. Adjustable Below-Knee Standard Prosthesis. As previously reported (BPR 10–8) 100 of these units were manufactured and are being distributed to VA stations on request for use as temporary prostheses. We are continuing our efforts to bring to a completion the final design of cosmetic covers for this unit. When an adequate cosmetic cover becomes available, adjustable below-knee standard prostheses will serve in both a temporary and a permanent capacity (Fig. 4).

Additional units are being ordered with several minor design changes. The socket adjustment plate of the quick-disconnect system will be made of aluminum since the previously used phenolic adjustment plate could not be readily machined to the required tolerances. This plate is also drilled and tapped to receive the socket attachment strap to permit interchangeability and reuse of the socket of the component. The maximum tube length has been increased from 8 to 12 in. to provide sufficient length for tall amputees with short below-knee amputations.

2. *Adjustable Standard Above-Knee* (*Multiplex*) *Prosthesis.* In early 1965 we described our original design concept and the potential advantages of this device (BPR 10–3). Since then we have periodically reported our progress in the development of the unit which has now reached a stage where we are considering bids for production engineering and fabrication of a limited number of devices. In its present configuration, to be known as the Model I, the unit includes a knee lock, variable mechanical friction knee control, and a complete alignment capability including individual adjustment by means of simple screw systems as in the Adjustable Below-Knee Standard Prosthesis. It offers options for a torque absorber, and it is capable of accommodating almost all of the commercially available hydraulic knee control mechanisms. Conceptually, this device is the core module of an above-knee prosthetic system whose applications range from the simplest immediate post-operative prosthesis to a permanent, sophisticated prosthesis incorporating the most advanced foot, shank, and knee mechanism. This versatility

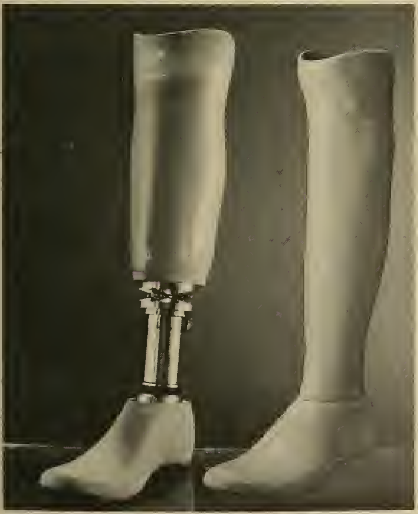


Figure 4.—VAPC BK Standard prosthesis (left) and most recent model of its cosmetic cover (right). The current production model includes the VAPC torque absorber just above the foot attachment plate.

stems from the modular design in which the basic unit conveniently accepts additional modules ranging from the simplest to the most complex available. Thus, it is conceivable that the basic unit may be furnished the patient on the operating table when the needs are crude alignment and perhaps knee stability. Within a short period as walking skill develops, more precise alignment is available and the required control of knee swing can be provided. The series of sockets from the original plaster-of-paris wrap to that of the final permanent prosthesis is easily installed. As a patient progresses to the point of discharge from the hospital, almost any of the available swing-control mechanisms and other components prescribed for the final prosthesis may be substituted. This gives the clinician the capability of continuously and conveniently modifying his prescription in accordance with the patient's progress and developing needs (Fig. 5).

We plan to issue these units on a routine basis in a program similar to that now in effect for the below-knee standard prosthesis. Initial use may be limited to temporary prostheses. As soon as adequate cosmetic covers are procured the full potential of these units will become available.

As the same time we are designing a second generation device to be called the Model II. While in the drawing board stage the Model II will permit us to accommodate newly developed but not yet commercially available

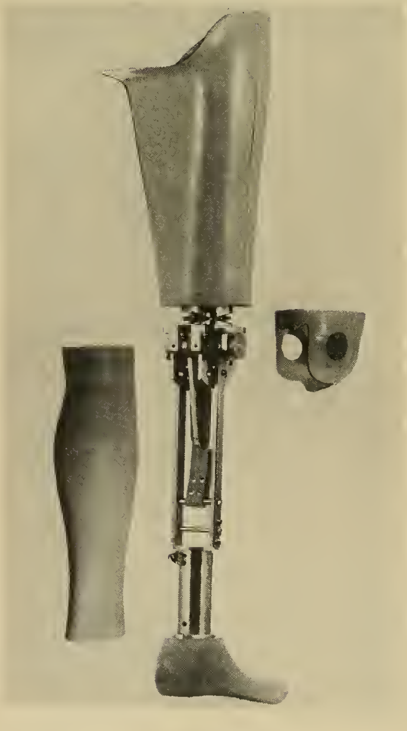


Figure 5.—VAPC Standard AK Prosthesis with cosmetic knee and shank covers.

devices such as the modified Mauch Model A knee control and perhaps a modified UC–BL pneumatic knee mechanism. Useful feedback from the field experience with the Model I will also be reflected in the design of the Model II.

C. Development (Techniques)

Direct Forming of Below-Knee Sockets. Polysar extruded into appropriately sized tubes has been increasingly used to mold below-knee sockets directly over patients' stumps (BRP 10–8). Twenty-four patients fitted during the past year with prostheses including Polysar sockets are still wearing them.

Fifteen patients have been wearing Polysar sockets for periods up to one year; nine additional patients have been fitted with temporary sockets of Polysar. The prescriptions for these patients varied according to need including all the conventional prosthetic feet, thigh lacers (three cases), and total contact sockets with foam ends. The nine temporary prostheses were fabricated with pylon-type shanks, and the permanent prostheses were fabricated with wood shanks. All the sockets were constructed on the PTB model. In some cases modifications of the socket were necessary due to stump shrinkage. This was routinely accomplished by reheating and reforming the Polysar socket according to the new requirements. In addition to the twenty-four unilateral amputees, one bilateral amputee with an above-knee and below-knee amputation has been wearing a below-knee Polysar socket and a conventional above-knee socket.

We are continuing to fit patients with sockets made of Polysar since no significant contraindications have been noted and the potential advantages of Polysar, detailed in previous issues of this Bulletin, are being realized.

Polysar in the form of extruded tubes is now being made available to suppliers of prosthetic and orthotic components and materials. For those who may wish to use Polysar to form below-knee sockets, a manual detailing the VAPC procedure is available on request.

D. Evaluation (Components)

Revised UC-BL Pneumatic Above-Knee Swing Control Mechanism. Fifty units, manufactured by the A. J. Hosmer Corporation of Campbell, California, have been delivered. Each has been inspected, and a representative sample has been retested for compliance with the original specifications. These units will be distributed to selected VA field stations as part of a clinical application study.

E. Evaluation (Techniques)

None.

II. UPPER-EXTREMITY PROSTHETICS

A. Development

VAPC Upper-Extremity Control System. In the previous issue of this Bulletin we reported an analysis of nine externally powered hands. Among our findings we noted that many brilliant concepts were embodied in some of the nine hands but that inadequate attention had been focused on the harnessing and control problems involved in utilization by a patient. With increasing frequency, development projects seem to be directed toward new or improved hardware without adequate consideration of, or relation to, a clearly defined problem of patients.

We believe that it is far more fruitful to base development projects on specific and precisely analyzed patient problems. A case in point is the standard above-elbow unilateral amputee whose catalog of problems is lengthy. The conventional above-elbow prosthesis usually consists of a terminal device, wrist unit, forearm, mechanical elbow with lock, socket, and standard above-elbow figure-8 harness. To operate his terminal device in a meaningful way, the amputee is required to flex his shoulder in order to flex the prosthetic elbow. Then he abducts and extends his shoulder in order to lock the elbow, an awkward motion which displaces the terminal device. After locking the elbow he continues flexing his shoulder in order to open or close his terminal device. Normally, he needs 2 to 2½ in. of excursion to flex the elbow and an additional 2 to 2½ in. of excursion to close or open the terminal device fully. After he has "used up" 4 to 5 in. of excursion he grasps or releases objects. At the extreme range of available excursion, control over terminal device force and position may not be optimum. It is also generally impossible for the above-elbow amputee to operate his terminal device simultaneously with elbow flexion or extension; the elbow must be locked prior to operating the terminal device. The amputeee, therefore, must operate sequentially, three separate "machines"—elbow lift, elbow lock, and terminal device.

A reasonably designed, electrically powered elbow could easily eliminate the need for locking and unlocking and reduce by half the total excursion required. Control over terminal device operation by means of muscles might well be superior to control by externally powered sources since much of the original feedback system including the residual tactile and proprioceptive receptors would be employed. From this viewpoint it would seem potentially advantageous to design an above-elbow prosthesis consisting of conventional components and an electrically powered elbow. Moreover, if this hybrid system could be controlled by the same number and type of control motions used in current conventional systems, a significant step forward in service to above-elbow amputees may be taken.

With this in mind we have designed a control system to extend and flex an electrically powered elbow and to open and close a terminal device by the same control motion conventionally used—shoulder flexion (Fig. 6). The device is designed to be attached to the control attachment strap (CAS) of the conventional above-elbow figure-8 harness and connected to the conventional Bowden control cable. Flexion of the shoulder exerts a pull through the CAS. An excursion of approximately ¼ in. and a force of 4 or 5 oz. closes a microswitch which causes an electrical elbow to extend. Continued

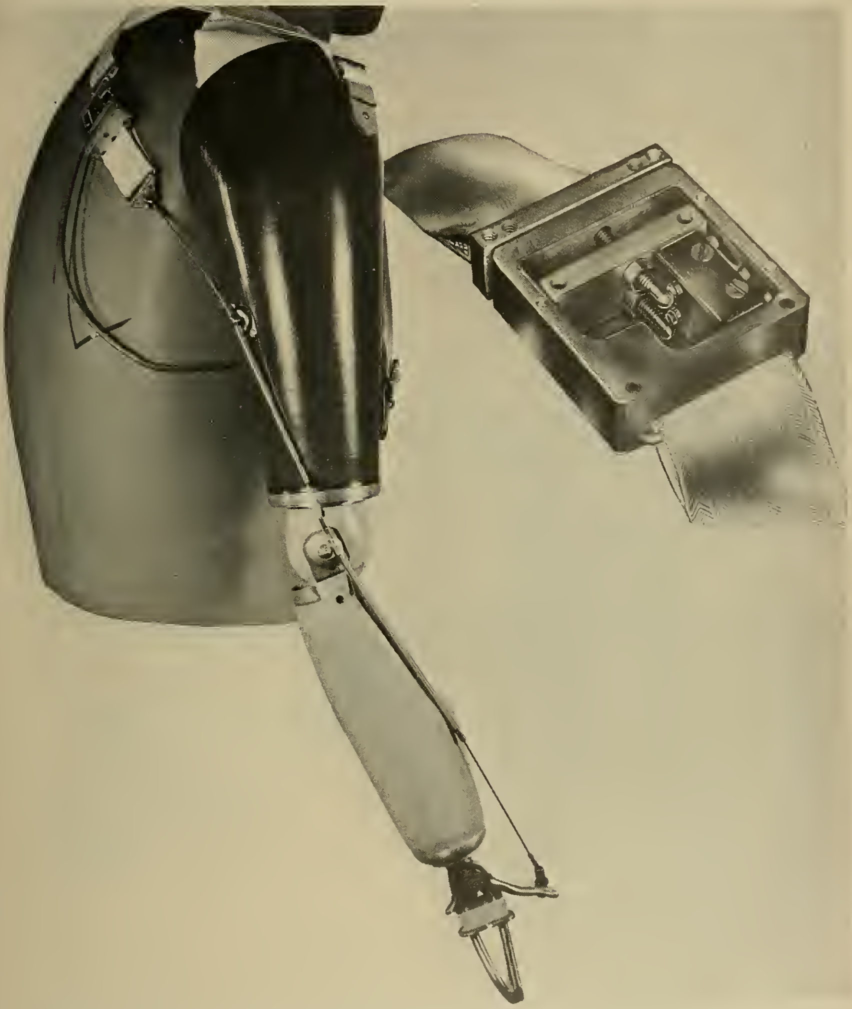


Figure 6.—Mounted on mannequin is prosthesis with electric elbow and VAPC control system installed in control attachment strap of conventional AE figure-8 harness. Inset shows position of two control rods and two microswitches which they depress and release as they travel under the pull of the control cable. Shown here is "neutral" position in which the two microswitch buttons are positioned in the detents of the conrol rods.

shoulder flexion, producing an additional excursion of ¼ in. and a force of approximately 10 oz., overrides the first switch and closes a second microswitch which causes the electric elbow to flex (Fig. 7). Continuing shoulder flexion beyond this point transmits force exerted by the muscle through the switch to the conventional control cable to actuate the terminal device (Fig. 8).

The principal advantages of this system are: 1. reduction of excursion required to operate the terminal device by approximately 2½ in.; 2. elimination of the elbow locking body motion—abduction-extension of the shoulder, elimination of the displacement of the terminal device during the elbow locking and unlocking cycle; 3. improvement of terminal device control owing to the greater length of the muscles while they are actuating the terminal device. Secondary advantages are: 1. extensive retraining of the patient is unnecessary since the same basic control motion—shoulder flexion, is employed; 2. the control switch is inserted between the control attachment strap of the conventional above-elbow harness and the Bowden cable system; 3. the elbow lock control strap is eliminated; and 4. the system can be used with any electrically powered elbow and any conventional terminal device.

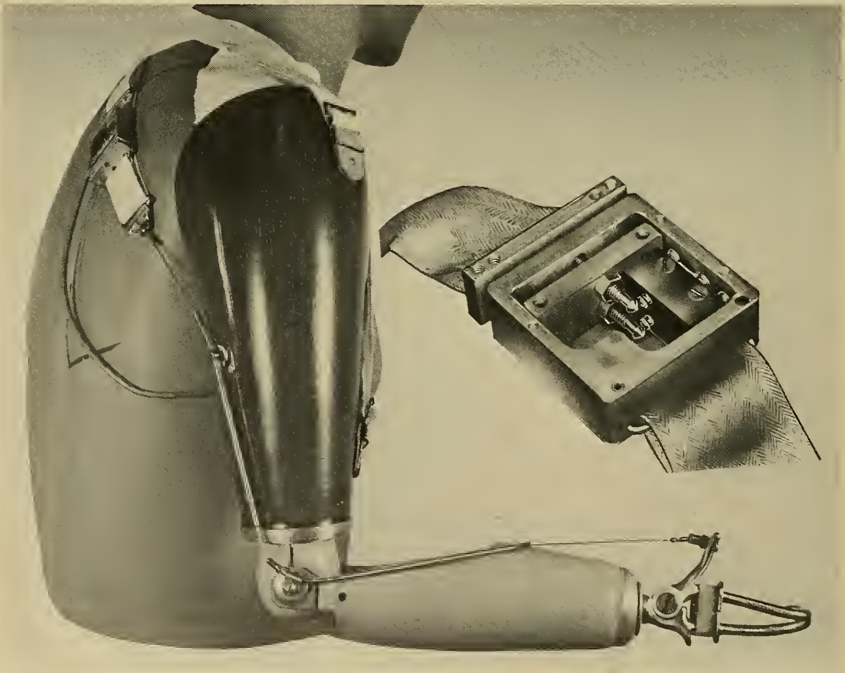


Figure 7.—A low force small excursion pull draws the control rod past the upper microswitch button (controlling extension) and into position to actuate the lower button to produce elbow flexion.

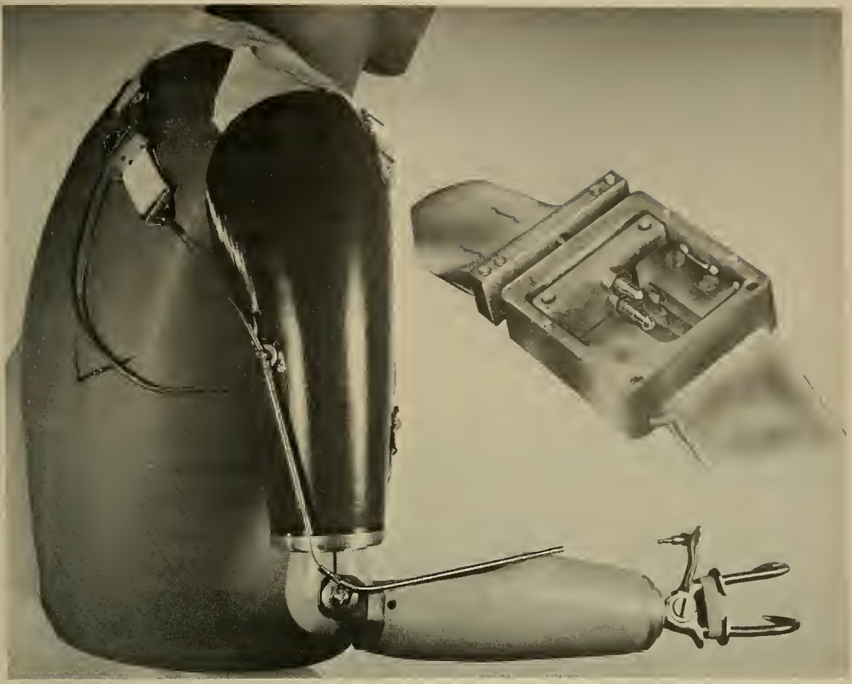


FIGURE 8.—Continued pull on cable moves both control rods off the microswitch buttons and transmits pull through the entire unit to control attachment strap and to control cable to actuate terminal device.

The model pictured in Figures 6, 7, and 8 is a prototype to enable us to determine the most advantageous force and excursion for controlling the elbow. Several models are being fabricated for laboratory studies with patients.

B. Evaluation (Components)

1. AIPR (*American Institute of Prosthetic Research*) *Externally Powered Components.* As reported in the previous issue (BPR 10–8) our research and evaluation program on the AIPR system has been completed. A report detailing several recommendations was submitted to the developer. Due to the accelerated pace at which the desired information was obtained, the developer has requested funds from his sponsor for a clinical field study to determine the utility of the AIPR pneumatic prosthetic system for adult bilateral arm amputees including shoulder-disarticulations and above-elbows. The aim of this project is to determine whether the current system is sufficiently practicable to be effectively applied in typical amputee centers, or whether the more highly specialized procedures previously employed in laboratory studies are required. VAPC is cooperating with Duke University Medical Center and the developer, Dr. Edward Kiessling, in conducting biomechanical studies and evaluation programs on new and improved models of the AIPR components.

2. *Evaluation of Externally Powered Hands.* In the previous issue of the Bulletin, we reported a detailed analysis of nine externally powered hands. As indicated in that report several of the hands were available to us for testing in the laboratory. Others were analyzed on the basis of information published by other agencies which evaluated one or another of the hands. We pointed out that certain of the apparently negative features we noted in particular hands may have been eliminated in subsequent models. One such case is the Beograd hand, an early version of which was discussed in our report. Since then we have in our possession a late, presumably production model of this unit (Fig. 9).

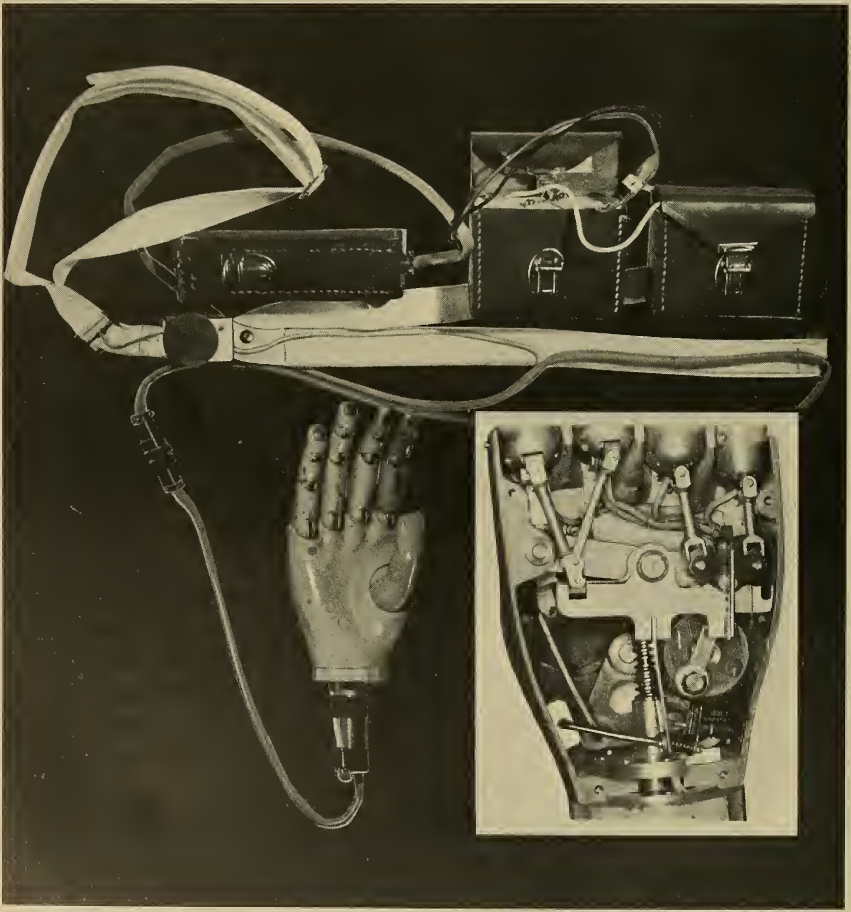


FIGURE 9.—Most recent model of Beograd hand with battery packs and amplifier section.

The current hand is reasonably anthropomorphic and can be covered with a cosmetic glove. The first metacarpal of the thumb is adducted, and the proximal phalanges of the fingers are longer than in a normal human hand.

The revised model retains the two modes of prehension: palmar and grasp. In palmar prehension the first and the index finger approximate the thumb as the ring and little finger continue closing and approximate the palm. In grasp, the thumb partially abducts and all four fingers approximate the palm.

The hand alone weighs approximately 25 oz. with another 44 oz. added by the battery and control package. Electrical power is supplied by four stacked silver-cadmium cells for a total voltage of 20 volts, and a current capability of 2 ampere hours. The maximum opening range is about 2¾ in. with a maximum prehension force of 5 lb.

The hand provides voluntary opening as well as voluntary and automatic closing in both modes of prehension. Information for the control unit comes from five sources: two in the harness and three in the hand itself. A microswitch and a potentiometer are mounted in one strap of the figure-8 harness, and as the wearer stretches the harness he releases the microswitch and turns the potentiometer; the harder he pulls the more the potentiometer turns. When he releases tension in the harness, the potentiometer returns and the switch resets. A second microswitch activated by the wiffletree push rod on the worm-gear drive is located in the hand. This switch is actuated whenever the fingers are in the extended position. On each of the fingertips is a pressure switch that is activated by contact with any solid object. The fifth source of information for the control unit is evidently obtained by monitoring the motor stall current.

In voluntary operation of the hand the direction of motor rotation is controlled by the microswitch in the harness which operates as an alternator; i.e., the first time actuated the motor will turn clockwise, the second time counterclockwise, the third clockwise, etc. The potentiometer in the harness controls the power available to the motor; i.e., under a weak pull the motor goes slow and with little force and as more force is applied to the potentiometer the speed increases.

The relationship between direction of motor rotation and hand operation is as follows: with the hand closed in palmar prehension, if the motor rotates counterclockwise, the hand will extend fully (actuating the microswitch in the hand) and then close in the grasp position; when the motor is rotated clockwise, the reverse sequence will happen. Thus, for the wearer to close the hand in palmar prehension from the open position, he must remember the last direction in which the hand was operated. If it was palmar, then he pulls the harness once with his force controlling the rate of palmar closure; if it was grasp he must "double shuffle" the harness to make the hand close in grasp. For grasp a similar situation occurs. Every time the motor is actuated it starts in the opposite direction to which it last ran.

Operation in the automatic condition has the same limitations as above, but the microswitch in the hand acts to preset the direction (the reverse of the last action), and actuating the pressure switches in the fingers make the hand close at maximum speed.

The Beograd hand remains a sophisticated design concept that attempts to more fully simulate the normal hand. Fully articulated fingers that close in two adaptive prehension modes is a unique feature. Closing on contact with an object is a characteristic of the normal hand and also unique among powered devices. The present operating sequence is fairly simple and should not require much training.

As an extension of these design studies of externally powered terminal devices, we have expanded the program to fit patients with currently available powered hands in order to evaluate their function. In this portion of the program we plan to fit below-elbow and above-elbow patients successively with each of the available externally powered hands. After a suitable period of training and use, the performance of each patient with each hand will be tested objectively. A comparative analysis of relative skill in prehension, positioning, and practical tasks will be obtained. The VAPC test procedure previously described in BPR 10–3, pp. 128–129, is being employed.

To date, the Canadian hand and the Viennatone hand have been installed in the prosthesis of a below-elbow amputee who previously wore a Becker Imperial hand, a "Muenster" type below-elbow socket, and an axilla loop below-elbow harness.

Both of these externally powered hands are operated by EMG signals from the wrist flexors and extensors, which respectively close and open the fingers of the terminal device. New below-elbow prostheses of the Muenster type were required in order to incorporate the electrodes of each system into the sockets. In the Canadian hand the entire fitting and preliminary training of the subject was done at the Montreal Rehabilitation Institute, Montreal, Canada. The Viennatone hand was fitted and the patient trained at the Bioengineering Research Service, VA Prosthetics Center. The subject's initial performance with each of the new terminal devices and his performance 1 month afterward were evaluated.

As shown in Table 1, there was little significant difference in the speed of performance regardless of the device used. Significantly more grasp and compression errors were made with the externally powered hands. However, clinical observation and patient reaction clearly indicated that the performance with both externally powered hands was far less tiring than with the Becker Imperial hand. Although the Viennatone hand was "slower" (two seconds versus one second) than the Canadian, the patient preferred it because of the "firmer grasp" (12–20 lb. versus 4+ lb.).

TABLE 1.—*Analysis of Hand Functions Performed with Three Different Hands*

TD test	Becker		Canadian		Viennatone	
	Position	Prehension	Position	Prehension	Position	Prehension
Time (min.)	3. 88	2. 00	3. 87	2. 42	3. 82	2. 20
Errors (numbered)	2 grasp	3 compression	7 grasp	10 compression	6 grasp	8 compression, 2 grasp
Subjective rating	Good	Fair	Good	Fair	Good	Good
Observation and patient reactions.	Required 2 rest periods during test. "Really have to work."	Failure on metal disk, metal square, metal triangle. Difficult to release—wedging in TD ball.	In hurry to grasp—would knock over objects.	Failed on *all* flat metal pieces. Content to grasp compressible objects with no thought to force required.	"This test required *more effort* than Canadian did."	Failed to grasp large metal triangle, metal disk, metal square. "Slower than Canadian, less sure than Canadian, but prefer Viennatone for *firmer* grasp."

These data are insufficient evidence to support conclusions on the relative functional utility of the three types of hands. During the continuation of the evaluation program the same subject will be fitted, trained, and tested with other devices and additional subjects will be recruited.

An example of other devices which will be evaluated is the Collins hand (Fig. 10), which demonstrates very versatile prehension and grasp patterns.

3. Fillauer Low Friction Transmission System. A sample of an upper-extremity cable transmission system manufactured by Fillauer Surgical Specialties, Inc. of Chattanooga, Tennessee, was evaluated. Designed to

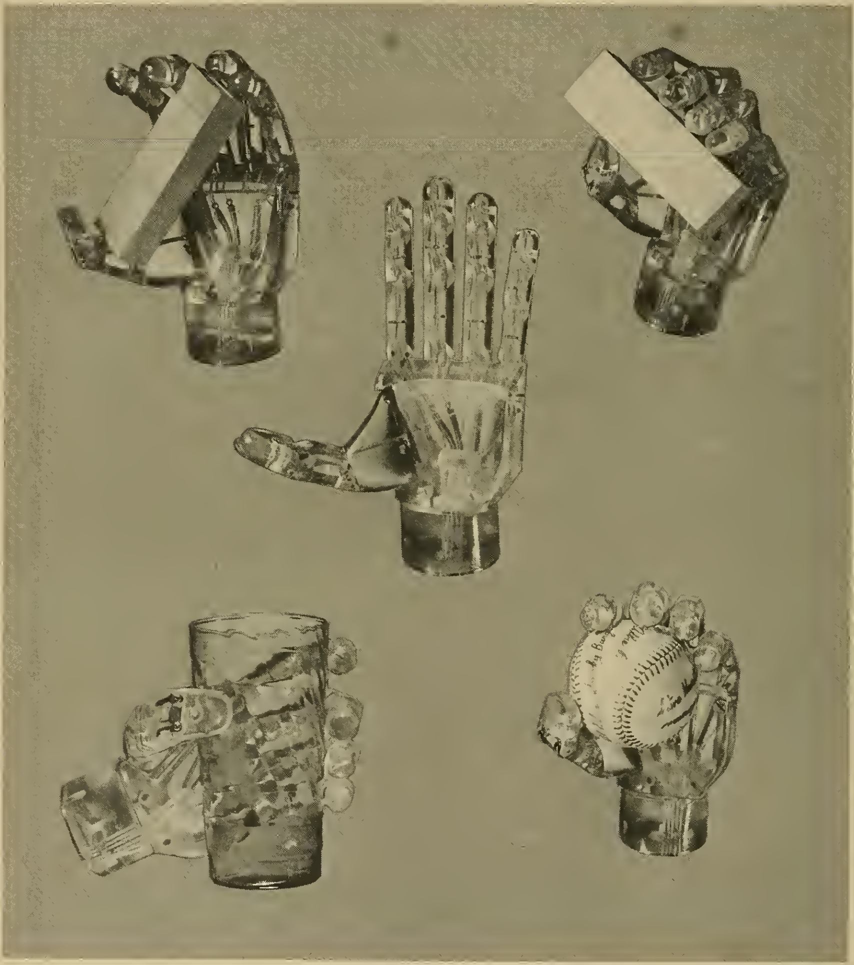


Figure 10.—Collins hand (center) has five active digits which enable it to grasp irregular objects at any angle of approach (above) and to "wrap around" cylindrical and spherical objects (below).

operate with very low friction the system consisted of: a. plastic transmission cable of spiral construction, .051 in. in diameter; b. Teflon liner with a wall thickness of .017 in.; c. heavy-duty steel housing; d. American Cable Company (ACCO) terminal fittings; and e. heavy duty hanger and cross bar (Fig. 11). The test procedures employed in this evaluation were the same as those used previously to evaluate cable transmission systems (BPR 10–8).

As shown in Table 2, the Fillauer Low Friction Transmission System elongated approximately 11 percent under 50 lb., a load which might normally be applied during use. When the 50 lb. load is removed, the cable material shortens but remains approximately 2 percent longer than its original length. These characteristics are quite similar to those noted in the Perlon Cable Transmission System in which similar elongation apparently did not constitute a deficiency when used by patients. Efficiency of the Fillauer Cable System in flexion and extension is comparable to the Bowden system and slightly higher in flexion than the Perlon system.

The tensile strength of the *total system* is comparable, if not slightly superior to, conventional Bowden cable systems. This may be due to the fact that the Fillauer system utilizes a heavier ball receiver (ACCO), the site of failure when the complete systems are tested. When tested without the ball receiver, the Fillauer cable breaks at the ACCO terminal fitting under approximately 115 lb. of tension. Under the same conditions, the standard Bowden cable withstands approximately 220 lb. The Fillauer cable without fittings breaks when loaded with 130 lb. which is comparable to Perlon. The Bowden cable breaks at 305 lb.

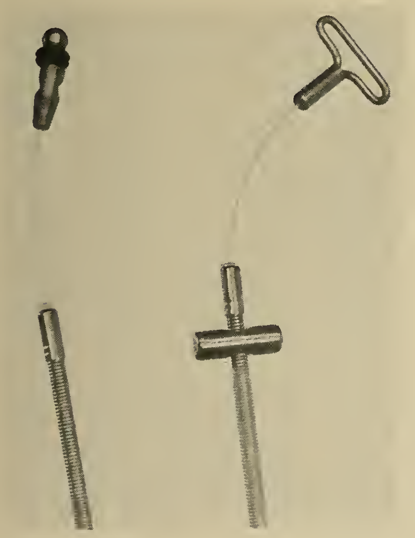


FIGURE 11.—Fillauer Low Friction Transmission System showing plastic transmission cable with Teflon liner and steel housing.

TABLE 2.—*Elongation, Efficiency, and Tensile Strength of Three Upper-Extremity Cable Transmission Systems*

System	Elongation percent (approx.)	Efficiency percent		Tensile strength, lb.		
		Flex.	Ext.	Test #1 Total system	Test #2 Without ball receiver	Test #3 Cable only
Bowden, conv. (standard) 3/64 in. steel cable, Teflon Spaghetti Tubing No. 15 AWG, standard steel housing, heavy-duty steel components.	0–1.5	79	93	92 Steel ball pulled out of receiver.	220 Cable pulled out of swaged harness connector fitting.	305 Cable broke at point of attachment to lower test grip.
Perlon cable 1/16 in. Nylaflow tubing 7/64 in. ID by 3/16 in. OD, heavy-duty steel components.	11–16			70 Cable pulled out of swaged ball fitting.	70 Cable pulled out of swaged ball fitting.	125 Cable broke within fixture attached to lower test grip.
A) Nylaflow tubing flared with cold tool.		68	91			
B) Nylaflow tubing countersunk on drill press.		68	91			
C) Nylaflow tubing flared with hot tool.		50	87			
Fillauer low friction transmission system. Transmission cable 0.051 in. in diameter. Teflon liner 0.017 in. thick. Heavy-duty steel housing.	11–13	80	94	105 Steel ball pulled out of receiver.	115 Cable pulled out of terminal fitting (ACCO).	130 Cable broke at point of attachment to test grip.

Since the tensile strength of both the Fillauer cable and Perlon is approximately the same, the greater strength of the *complete system* may be attributed to the way the cable is connected to the ACCO fittings. The slight increase in efficiency, 10 percent in flexion and 3 percent in extension, may indicate that the Teflon of the Fillauer system is superior to Nylaflow of the Perlon system in reducing friction. However, the Teflon liner deteriorates more under the grating effect of the braided cable used in the Bowden and Fillauer systems (Fig. 12).

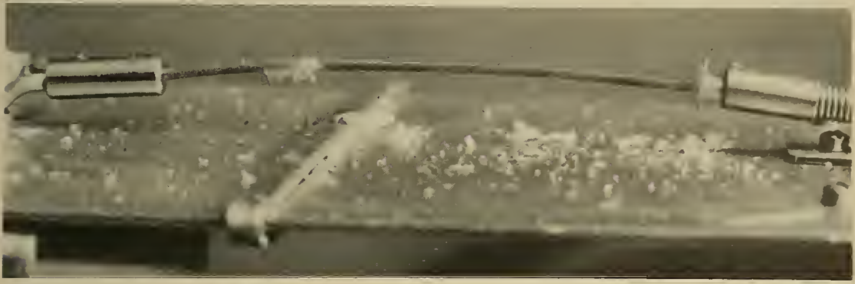


FIGURE 12.—Abrasion of the Teflon liner by the cable.

Both the Fillauer and the Perlon cables take a permanent set under tension, a matter which may affect long term durability. Several Fillauer Systems will be fitted to patients to determine its utility.

4. Humeral Rotator. In continuation of our studies to determine the utility of active humeral rotation for above-elbow and shoulder-disarticulation amputees, two samples are under investigation. As described in BPR 10–8, a laboratory model of an electrically powered, shear switch-controlled, humeral rotator was fabricated and installed in the prosthesis of an above-elbow amputee. The subject was trained to use the device and his performance of routine tasks is being studied.

The second system is a mechanical humeral rotator designed by a bilateral above-elbow amputee, Mr. Joseph Ivko, for his own use. As shown in Figure 13a, the device consists of two disks, the lower of which rotates with the elbow and forearm. Rotation is adjustable through a range of approximately 180 deg. A spring-loaded plunger locks the unit in any of seven positions. The humeral rotator is controlled by the same body motion used to lock and unlock the elbow; it is unlocked by a greater range of abduction-extension than used for locking the elbow. The elbow therefore must be unlocked to operate the humeral rotator. Internal rotation is actively controlled by shoulder flexion and external rotation is passively controlled.

Control cables for the elbow and the humeral rotator are mounted on the anterior portion of the humeral section and attached to the anterior sus-

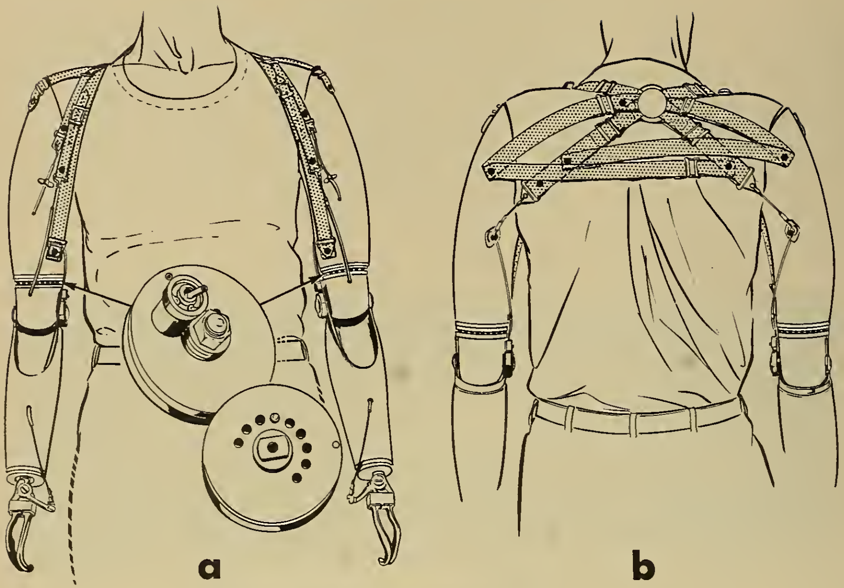


Figure 13.—(a) Mechanical humeral rotator, designed by Mr. Joseph Ivko, permits manual locking and unlocking of two plates mounted between elbow turntable and elbow to provide simulated humeral rotation. (b) Posterior view shows medial control cables which serve to rotate forearm internally when humeral rotator is unlocked.

pension strap of the harness. Several models of this device have been ordered for evaluation.

C. Evaluation (Techniques)

Direct Forming of Below-Elbow Sockets. On the basis of our experiences in fabricating below-elbow sockets of Polysar it has become apparent that forming a Polysar socket directly on the stump is a very simple technique. The use of Polysar in fabricating a *conventional* below-elbow prosthesis eliminates the need to: a. make a plaster-of-paris wrap cast, b. pour a positive cast, c. modify the positive cast, d. make a wax check socket, and e. laminate the socket. All of the other fabrication procedures with respect to wrist fittings, elbow hinges, harnesses, and control systems, are unchanged. New York University has undertaken a program to evaluate the fabrication procedure and the general utility of below-elbow prostheses constructed with Polysar sockets (Fig. 14).

Polysar in the form of extruded tubes is now being made commercially available through suppliers.

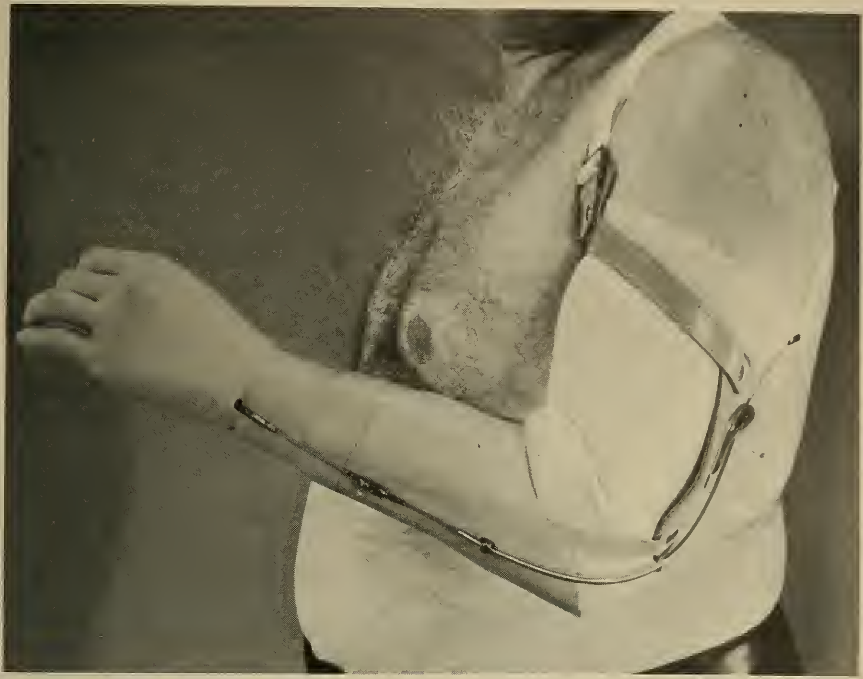


Figure 14.—Completed BE prosthesis with Polysar socket.

III. LOWER-EXTREMITY ORTHOTICS

A. Development

1. *Survey of Brace Components.* In the previous issue we published a list of lower-extremity brace components now in general use as indicated by their appearance in manufacturers' catalogs and prescription forms. The list was arranged in categories relating to the segment of the lower limb to which they are applied. To determine the extent to which these components are used in their purported applications we have conducted a survey of 28 VA Orthopedic Brace Shops. The results of the survey, detailed elsewhere in this issue, were highly significant.

2. *Arch Supports.* In a previous issue (BPR 10–7) we reported our efforts to utilize Spence-Gel in foot appliances designed to reduce plantar discomfort and calluses. Spence-Gel is a stable, chemically inert, silicone gel whose consistency is similar to that of human fat tissue. Foot appliances constructed with sheets of Spence-Gel were fabricated for two subjects. One had a history of callosities under the third metatarsal head that required the attention of a podiatrist at least once a month, and the other patient previously wore Schaeffer combination arch supports with two longitudinal steel shanks and a high metatarsal elevation.

Both subjects were provided with innersoles fabricated with ¼-in.-thick sheets of Spence-Gel in compartments under the heel, medial arch, and metatarsal region. These supports were worn by both patients for approximately 5 months with positive results. Both found the Spence-Gel supports extremely comfortable. The visits of one subject to his podiatrist were sharply reduced and the second subject reported substantial reduction of the pains he typically experienced in the lower calf and the plantar surface of the foot.

However, after 4 to 5 months of wear the Spence-Gel material extruded between the top and bottom sections of the support and through the stitches of the separate compartments into adjacent areas between the top and bottom sections. It has been impossible by stitching the top and bottom layers of the support, to contain the load-absorbing material which is subjected to high forces in standing and walking. With each step the full body weight, plus the inertial forces of movement, is applied to relatively small areas of the sole creating high pressures which cause the material to displace between adjacent stitches.

Due to the clearly positive results obtained from our experience with patients, we are continuing our efforts to package the material in a way to prevent unwanted displacement. Two methods are being investigated. In one we employ vinyl sheeting on which we deposit the Spence-Gel to conform to the required size of the areas under the heel, medial arch, and transverse arch. The vinyl sheet is then folded over and heat-sealed to enclose the Spence-Gel in compartments and to finish the lateral border of the appliance. The second method consists of depositing the material on a rubber sheet which is then vulcanized to enclose the gel to maintain it in its proper position.

B. Evaluation (Components)

1. VAPC Modular Single-Bar Braces. Our efforts in designing and developing single-bar (unilateral upright) braces have been described in previous issues. In BPR 10–1 we reported a measure of success in fitting single-bar leg-thigh braces to victims of polio, multiple sclerosis, paraplegia, and hemiplegia. The obvious advantages of the single-bar construction include the reductions of weight and bulk with a consequent conservation of energy by eliminating the medial bar.

Furthermore, the alignment of a single-brace joint to coincide with the anatomical knee center is a far simpler procedure than aligning two brace joints. Tibial torsion is more easily accommodated, and unwanted transverse rotation at the hip is more effectively controlled. Relative motion between the sidebar and the limb is minimized by specially designed thigh bands and calf cuffs. The thigh and cuff bands, with anterior openings, encircle about two-thirds of the extremity, providing more support than the half band generally used with double-bar braces. In effect, the tibia and the femur substitute for the medial bar due to the fit and configuration of the bands and cuffs.

In BPR 10–2 we reported our work in developing a single-bar brace construction for leg braces ("short leg brace"). We described a brace consisting of a band, and as an innovation, a lateral spring-loaded round sidebar and a 90 deg. plantar-flexion stop. The design of the spring-loaded sidebar permits axial displacement, transverse rotation at the mechanical ankle joint, and possible eversion and inversion of the foot.

The key components in these systems are the leg-thigh brace calf and thigh bands and the spring-loaded sidebar (a component that might also be useful for some patients fitted with leg-thigh braces as well as leg braces). We have therefore designed a modular brace system, some of whose components are interchangeable and serve for both leg and for leg-thigh braces. Moreover, the system permits a wide latitude in brace prescription since it offers options of solid or spring-loaded sidebars, solid or spring-loaded ankle joints, and lever lock or free knee joints. Stirrups, calf bands, and thigh bands are standardized, and a hip joint is available that offers the option of free motion or provides a positive stop.

As shown in Figure 15 the leg brace and the leg-thigh brace are constructed of the basic stirrup and ankle joint. The leg brace is complete with conventional calf band. The leg-thigh brace shown incorporates the spring-loaded lever lock knee joint.

The VAPC modular single-bar brace system has been developed to the point where the Pope Brace Company was awarded a contract to make a limited quantity of the components for evaluation in several VA Orthopedic Brace Shops and in the facilities operated by several members of the CPRD Workshop Panel on Lower-Extremity Orthotics. As received from the manufacturer, the ankle joints, knee joints, and all joint bushings are made of hardened 410 stainless steel, and except for the lever lock knee joint, are designed to accommodate needle thrust bearings (Fig. 16). The stirrup, the pelvic upright, and the calf and thigh bands are made of 304 stainless steel because these components usually require extensive bending and cold working. All of the joints, including the stirrups and bands are neuter, that is, they can be used for either right or left extremities. The joints are designed to accommodate $\frac{5}{16}$ in., round, stainless steel, aluminum or synthetic bar uprights; the joints can be modified to accept a $\frac{3}{8}$-in.-round bar for heavier patients. General purpose Loctite, Type B (7–10) is used to secure the joint bushings and screws. Components for both leg-thigh and leg braces will be made available to other facilities for limited field evaluation.

2. *AMBRL Fiberglas-Epoxy Drop-Foot Brace.* The U.S. Army Medical Bioengineering Research Laboratory has designed a drop-foot brace in which Fiberglas-epoxy rods form the uprights. These rods, fabricated from Scotchply Reinforced Plastic, Type 1008, manufactured by the 3M Com-

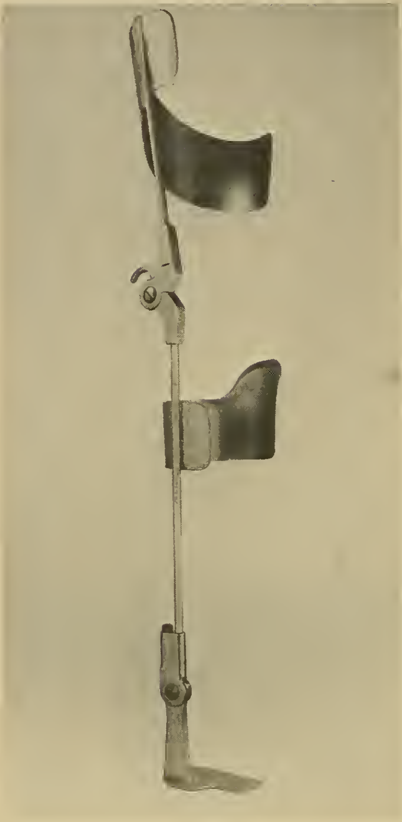


Figure 15.—Leg and leg thigh brace assembled.

pany of St. Paul, Minnesota, are pre-impregnated epoxy Fiberglas available in rolls of various widths.

A strip of the material is cut to the desired length. The tape is then rolled longitudinally as tightly as possible until a round rod is obtained (five strips of $\frac{3}{4}$-in.-wide tape will produce a rod of $\frac{1}{4}$ in. diameter; four strips will produce a rod of $\frac{7}{32}$ in. diameter; three strips, a rod diameter of $\frac{3}{16}$ in.). The uncured rod is then spirally wrapped with Tedlar, a polyvinyl alcohol; slight but uniform tension is applied during the winding. After sealing the rod at both ends with Tedlar release film, the wound rods are laid on a flat surface and cured for approximately 2 hours, at 160 deg. ±5 deg. C.

After consultation with AMBRL, we fabricated braces with straight Fiberglas uprights and a flexible leather cuff. In addition, we modified the shoe attachment using a length of $\frac{3}{16}$ in. ID stainless steel tubing to receive the Fiberglas uprights. The center section of the tubing is flattened and a stainless steel tongue is soldered to the flattened portion (Fig. 17).

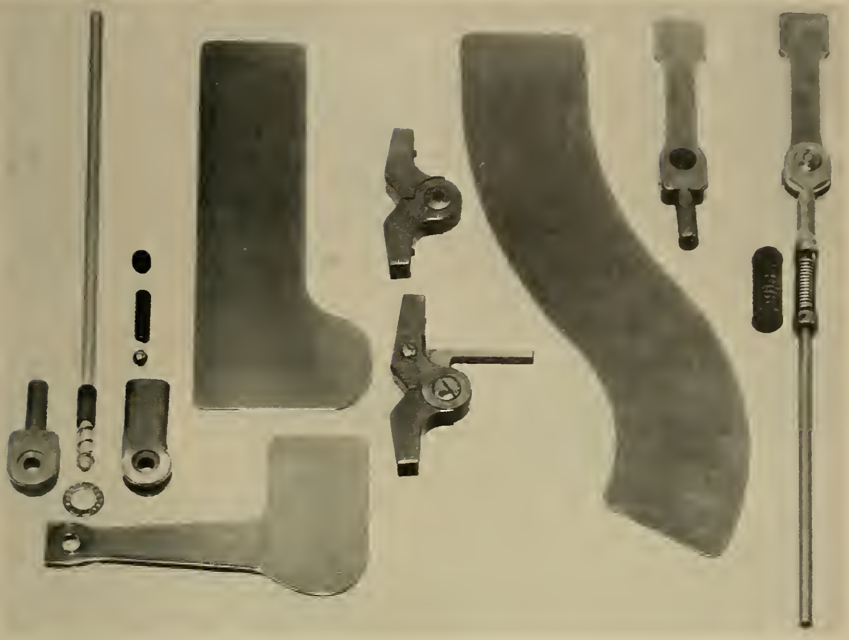


FIGURE 16.—VAPC Single-Bar Brace modules.

To date, we have fitted six drop-foot braces of the Fiberglas-epoxy type. The patient reaction to these braces has been favorable and we have not experienced fabrication difficulties or failures.

Since the procedure for handling the pre-impregnated tapes is a hand process subject to variation, we are now studying the use of prefabricated rods of the same, and possibly other materials.

C. Evaluation (Techniques)

Measurement of Foot Parameters. It is generally acknowledged that research and evaluation relating to the design and utility of appliances for the foot have not kept pace with prosthetics and orthotics research in general. One of the major impediments to progress in this field has been the difficulty of measuring and evaluating foot function. including motion at the ankle and subtalar joints as well as within the foot. Design and development in this field as in any other must be based on an adequate body of reference data to describe problems objectively and to make reliable observations for comparison. The collection of useful reference data depends on the existence of adequate instrumentation for recording appropriate parameters. To date, we have been handicapped by our inability to measure and record significant data at the shoe-ground and foot-shoe interfaces, and at the subtalar and ankle joints as well.

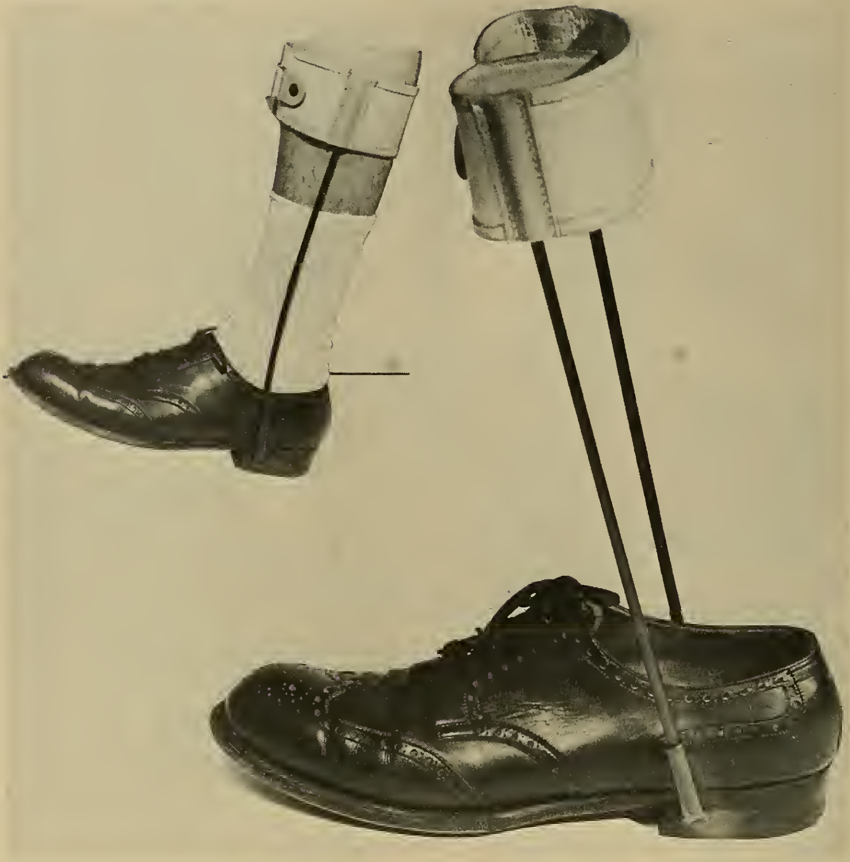


FIGURE 17.—AMBRL Fiberglas-epoxy sidebar.

Traditionally, kinetic factors related to the interaction of the foot and the ground have been measured by the use of force plates. Force plates are particularly effective in studying normal gait patterns and in evaluating the utility of prostheses and in some cases braces. Force plates do not accurately reflect, however, the instantaneous transition of weight across the entire surface of the foot; they only provide the "average" center of pressure at any instant during the stance phase. Areas of high pressure and shifts of pressure foci from one point to another are not readily revealed.

Photometric techniques in the form of "stick" pictures, cyclograms, and motion picture photography have also been used to study the effects of various pathological conditions on angular motion about the major joints on the lower extremity. Angular rotation about the ankle, knee, and hip has been measured by means of potentiometers mounted at the approximate centers of rotation at each of the major joints.

In dealing with problems of the foot, we are considering principally problems related to pressure distribution on the plantar surface of the foot and with foot balance, i.e., attitudes and motions of the subtalar and ankle joints. We are also concerned with the *effects* of foot/ankle dysfunction on the total gait pattern. Most of the currently prescribed appliances for the foot are intended to relieve or redistribute pressures on the sole of the foot and/or to control motion of the subtalar and ankle joints by restricting unwanted motion. To describe adequately the function of the foot and to evaluate the effects of foot appliances, we need to measure the pressure patterns on the sole of the foot both statically and dynamically. Adequate pressure data would provide the most direct indications of both the requirements for, and the effectiveness of, appliances. However, dysfunctions of the foot of any kind have second order sequelae in disrupting the normality of the total locomotion pattern. It is also necessary therefore, to study such significant gait factors as the pattern of weight application to the ground and rotations about the major joints. At the present time, the force plate and the photometric "stick" pictures provide adequate measurements of the latter two parameters. Pressures on the sole of the foot during walking have been extremely difficult to measure.

In the past, Ped-O-Grams, foot switches, and glass walkways did not provide adequately sensitive and reliable measures of the pressures applied between the foot and the shoe, between the shoe and the ground, or between the foot and the ground.

In BPR 10–4, pp. 161–164, we reported our efforts to develop appropriate instrumentation and techniques for objectively measuring weight-bearing patterns, foot balance, and other gait factors of patients fitted with appliances designed to support the foot and the arch. Pointed out were the difficulties of collecting objective data on such matters as "foot balance," pressure distribution, and weight transition during stance phase. We described our early efforts to utilize for this purpose the barograph, an instrument developed initially by Elftman (3) and refined at the University of California at Berkeley (4). The barograph permitted us to photograph the pressure distribution pattern over the entire surface of the foot or shoe but the data were difficult to quantify. Since that time we have designed a new barograph based on the original principle. The sensitivity and reliability of the new model approach the limits for such an instrument (Fig. 18).

The barograph consists essentially of a plate of glass with a high intensity light source around its perimeter. A modified polyvinylchloride (PVC) mat cut in a pattern of precisely dimensioned pyramids is placed on the upper surface of the glass plate. The entire plate, covered by the mat, is set above a parabolic mirror angled at 45 deg. to the lower surface of the plate.

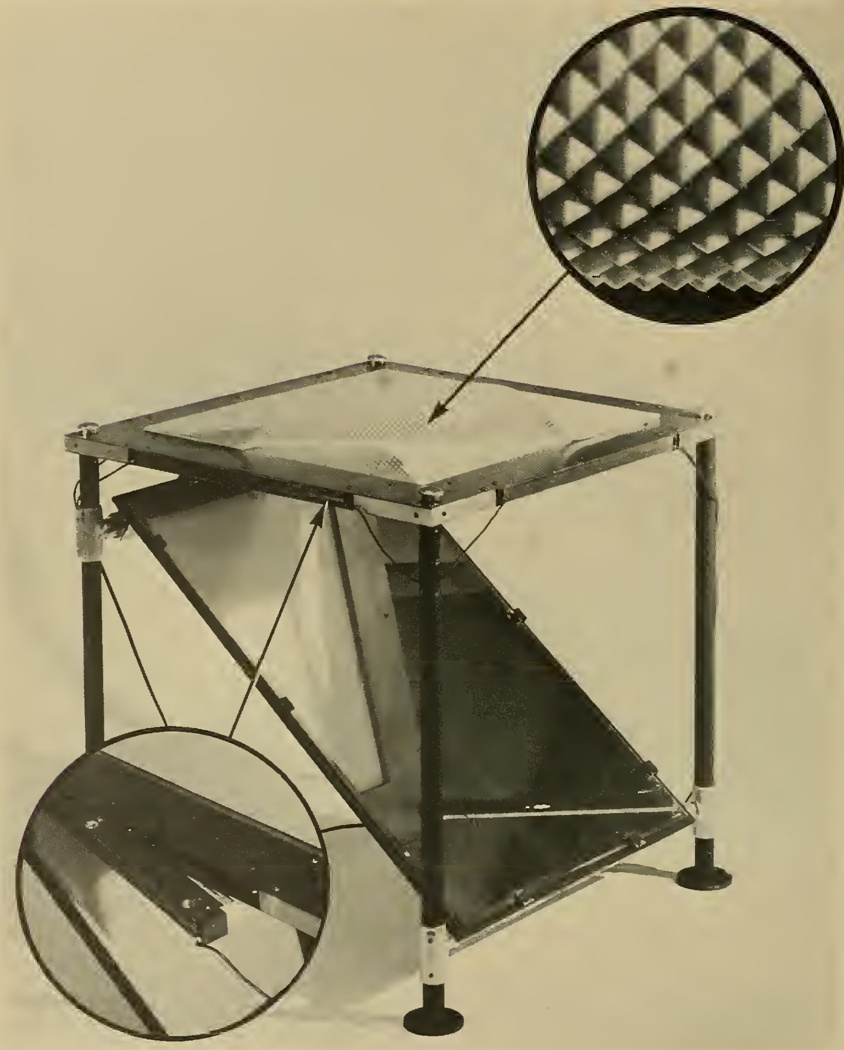


FIGURE 18.—Portable version of barograph designed to be placed between two tables to provide an appropriate walkway without elaborate installation. Lower inset shows high intensity lights. Upper inset is detail of mat.

Light is introduced through the edge of the glass in such a manner that it strikes the surface of the glass at a greater angle than the critical angle for a glass-air interface. The light "bounces" between the two parallel sides of the glass being reflected internally with minimal loss. When a pyramid of modified polyvinylchloride is pressed against the glass by the weight of the foot, the local critical angle is greatly increased. This results in light crossing the interface, diffusing into the pyramid, and then being reflected down through the bottom surface of the glass plate. The higher the force compressing the pyramid onto the glass the larger and the more intense the lighted interface area becomes. The critical angle is changed so markedly because the ratio of the indices of refraction from glass to PVC approaches unity while the ratio of the refraction indices of glass to air is above 1½.

Used in conjunction with force plates and stick pictures, the barograph provides us with the most useful and complete set of data on foot function obtained to date. While very far from perfect, this system enables us to record pressure between the foot or the shoe and the ground and to relate these pressures to other kinetic and kinematic factors. For example, in order to study the effectiveness of an appliance for the foot, we can record the pathological condition as a frame of reference by obtaining force plate recordings, stick pictures, and barograms of the subject standing and walking (if possible) without the appliance. This procedure is repeated when the patient stands and walks with the appliance and the data obtained can then be compared to the previous record. If the device was prescribed to redistribute pressure on the sole of the foot, the barogram would reveal the changes due to the appliance. The effects of the device on the kinetic and kinematic factors of gait can also be determined by comparison.

This system was recently employed to evaluate the effects of an orthopedic appliance worn by one patient (Subject A). Shown in Figure 19 is a static barogram of the foot pattern of a 42-year-old, 146-lb. patient with traumatic amputation of phalanges II, III, IV, and V including portions of the metatarsal of the right foot.

The right shoe is built over a Levy mold, which includes a toe filler made out of soft cork. There is a long steel spring (extending from heel to toe) in his right shoe. A ⅛-in.-thick sponge rubber insole was placed on top of the Levy mold and lasted with the shoe. The lateral quarter and vamp of the right shoe have been padded with foam rubber. After the shoe was completed, a ⅛-in.-thick sponge rubber piece was cemented on the inner side of the toe filler. The left shoe was made over a custom-fitted last and had no orthopedic features.

The upper half of Figure 19 shows pressure patterns of the patient without shoes on which is observed a relatively normal weight-bearing pattern on the left foot, although somewhat less than normal weight is carried on the phalanges in general. The right foot shows obvious concentrations of pressure on the heel and under the head of the first metatarsal. Clearly revealed is a compensatory adduction of the great toe of the right foot in an effort to maintain lateral stability in the absence of the four smaller toes. When full weight is borne on the right foot alone, there is a marked increase in the pressure on the extreme distal tip of the right

SUBJECT A

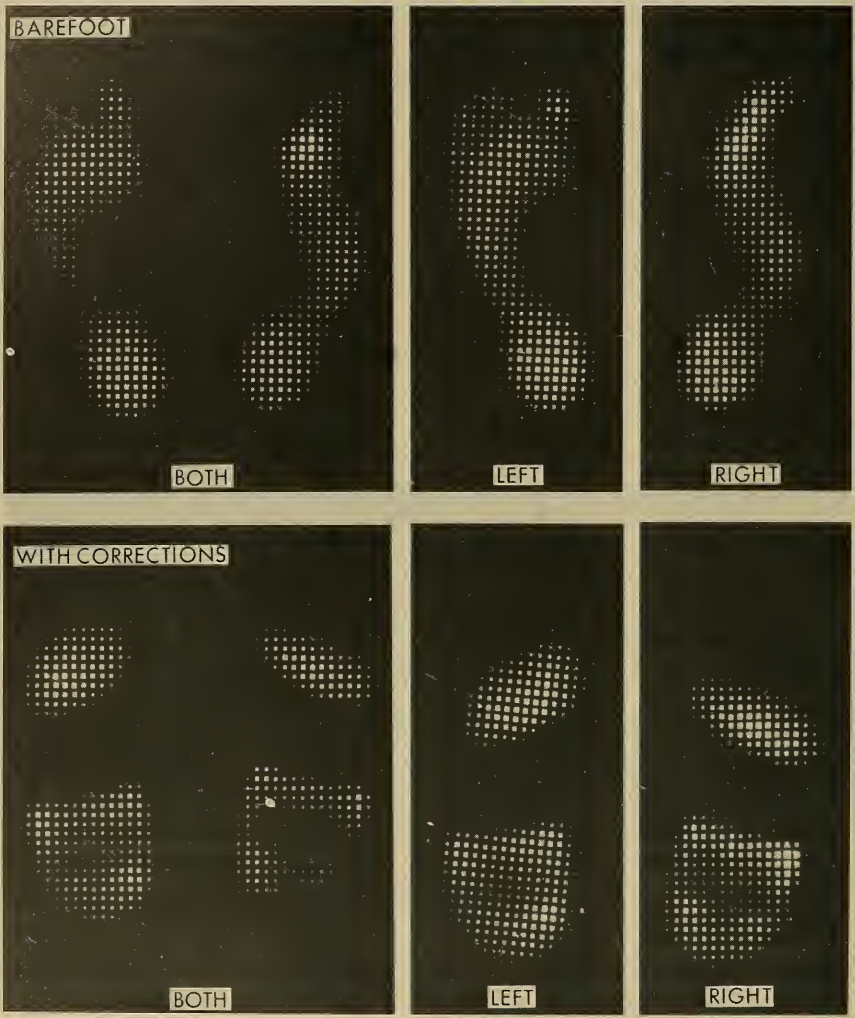


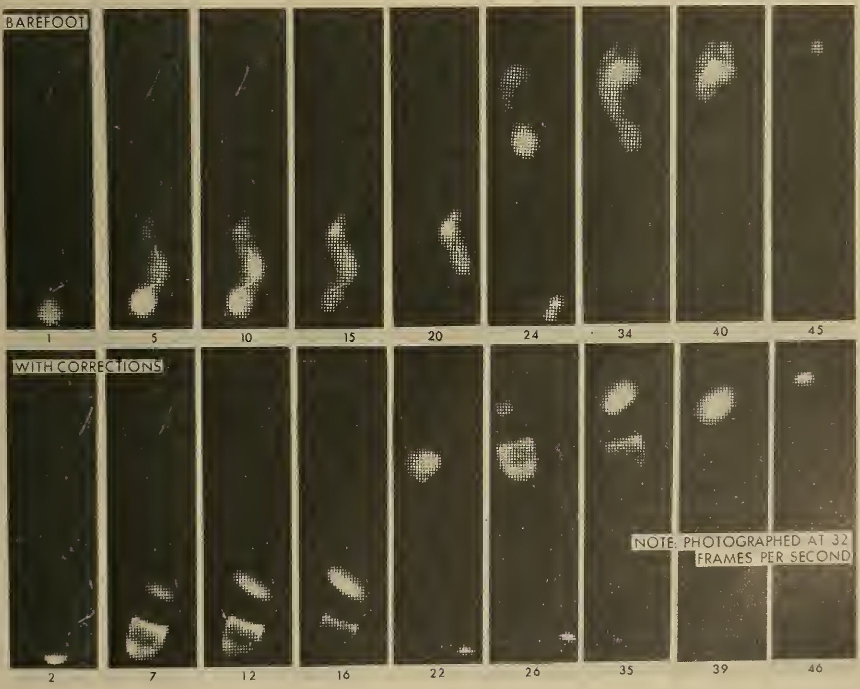
Figure 19.—Static barogram of Subject A with amputation of phalanges II, III, IV, and V standing barefoot (top) and with shoes (bottom). Barograms marked "left" mean all weight placed on left foot; those marked "right" indicate weight only on right foot.

toe. The lower half of the illustration shows the weight-bearing pattern of the patient wearing his orthopedic shoe. The distribution of weight seems relatively normal with perhaps more weight borne on the unamputated foot when standing erectly. When standing on the right foot alone, the barogram reveals a very high concentration of pressure on the right breast of the heel.

The upper half of Figure 20 shows the pressure pattern of the patient's right foot and the transition of weight onto the left foot. Reference to frames 20–40 reveals a high concentration of pressure on the first metatarsal head of the right foot (frame 20) as compared to the more evenly and centrally distributed pressure on the sound foot (frame 40) at toe-off. The lower half of the illustration, a barogram of the patient walking with his appliance, shows a reasonably normal redistribution of weight across the plantar surface of the foot. Despite the correction, very little weight is transferred forward to the metatarsal ridge. In contrast, the left sound foot (upper portion of frames 26–46) transfers the weight more evenly from the heel to the ball to the tip of the shoe.

In Figure 21 the linear displacements of the patient's hip, knee, and ankle and their angular rotations are compared with those of a typical normal subject. Of particular interest are the differences in the displacement of the hip and the flexion of the right knee when the patient walked barefooted and with his correction provided by the orthopedic shoe. Stance-phase time and knee-flexion range on the right foot were reduced when he

SUBJECT A



NOTE: PHOTOGRAPHED AT 32 FRAMES PER SECOND

Figure 20.—Dynamic barogram (selected frames) of Subject A barefoot (top) and with shoes (bottom).

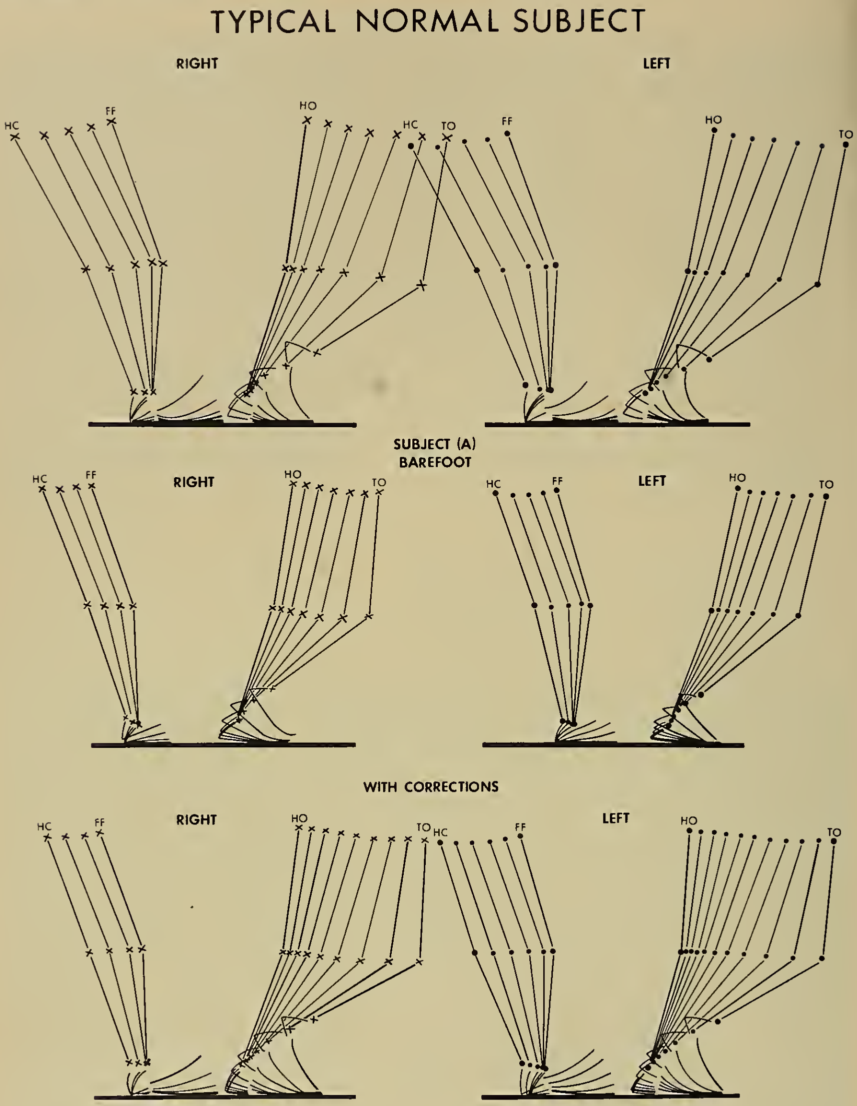


Figure 21.—Motion of Subject A's hip, knee, ankle, and foot compared to typical normal person (top).

walked barefooted. With the correction, he achieved a more normal pattern as shown by comparison with the left foot and with the typical subject.

Figure 22 shows the force plate record of the loads applied by the patient to the ground in comparison with the record of a normal typical subject. As expected, in the absence of four toes on the right foot there was very little, if any, push-off. Of special interest is the jog in the first peak of the left or normal foot indicating an uneven transition of weight off the great toe of the right foot.

Despite the difficulties of reducing data of this type and the special equipment required, the system provides the most definitive picture obtainable at this time..Efforts are being made to refine the data collection battery by the use of newly developed pressure gages which can be inserted in the shoe.

A portable version of the barograph is being routinely used in the Orthopedic Shoe Service of this Center to record the weight-bearing pattern of patients fitted with custom orthopedic shoes. Permanent records obtained

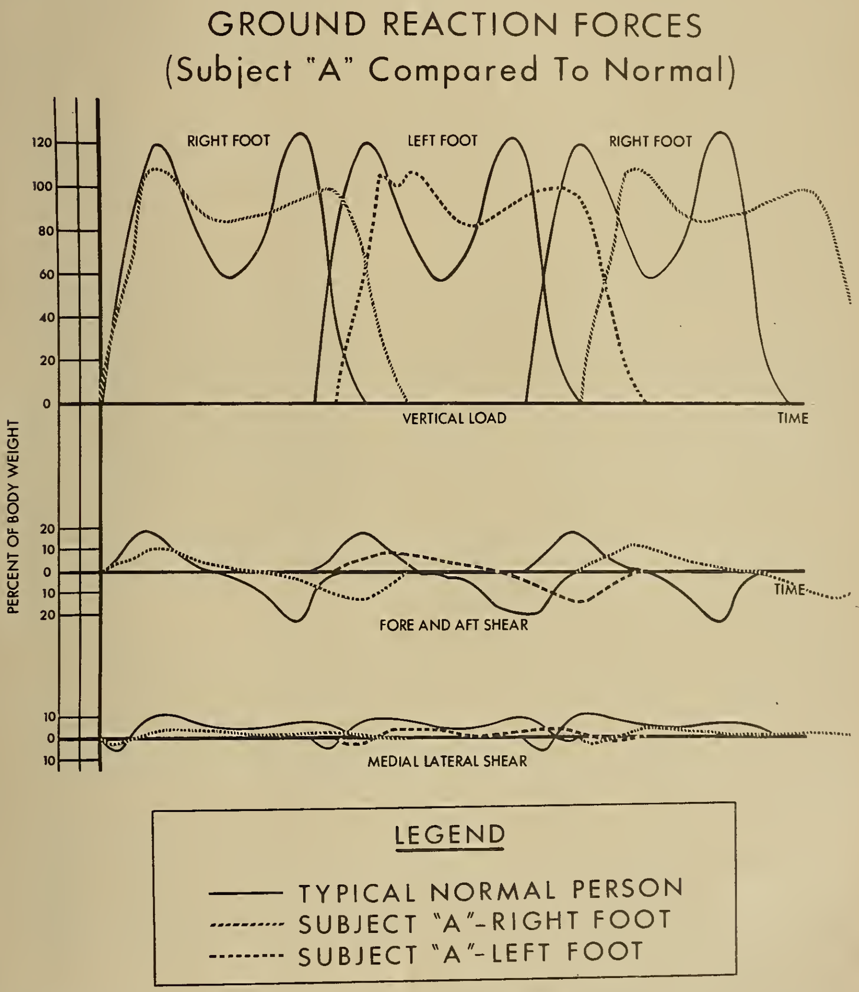


Figure 22.—Vertical load and shear forces of typical normal person compared to Subject A.

by new prescription and on worn shoes are being used to study the effects of wear on foot balance and weight distribution.

IV. ORTHOPEDIC AIDS

A. Development

None.

B. Evaluation (Components)

1. *Home Stairway Lift.* This report is presented with a view toward describing some of the fundamental problems associated with the design of home stairway lifts. We are frequently asked to evaluate designs of this nature and our analyses reveal the prevalence of two basic failings. Designers are often preoccupied with the details of materials and mechanical features to the extent that they overlook the biomechanical requirements involved in the use of the device by a patient in his home. Secondly, there is a tendency to design for a specific patient and to assume that what may be highly useful for one patient extends to an entire class of handicapped individuals. As the following analysis is intended for the guidance of developers, the full identification of the device is withheld.

Twenty-four drawings (photos were not available) were examined detailing the construction, materials, dimensions, and assembly of a device which is intended to function as an elevator to enable paraplegics and other disabled persons to ascend and descend a flight of stairs in the home. The unit is designed to permit a wheelchair to be rolled onto the platform of the "elevator car." The car is lifted and lowered by means of a continuous chain which is driven by an electric motor mounted on the floor at the foot of the stairs. The chain is encased in a housing which is mounted on a wall alongside the stairs and the "car" rolls on three rails, two below the chain housing and one within the chain housing. Switches to control ascent and descent are located at the head and foot of the stairs.

This device is similar in concept to several commercially available home elevators. It is designed to lift the patient in his wheelchair while all but one of the others require the patient to transfer from the wheelchair to the elevator seat. The following comments, noted in our analysis of one particular design are indicative of a general failure to consider the conditions of use when designing home elevators for handicapped persons.

a. The wheelchair platform is 36 in. wide and although it may swing up to clear the stairway for other use, it precludes the use of a stairway while the elevator is in operation. This is potentially dangerous in that children may be trapped on the stairs while the chair is moving or objects left on stairs may be damaged or cause damage.

b. There is no apparent provision for easy placement of the chair on the chair platform. Since the platform is approximately 5 in. off the floor, it would appear that the chair and patient must be lifted and placed on the platform. A similar problem would be faced at the head of the stairs in rolling down from the platform to the landing.

c. The system is unsafe in that there appears to be no provision for automatically maintaining the car's position during ascent or descent in the event of a mechanical failure of one of the attachment or support links.

d. The control system is unsafe. Failure of the limit switch, either mechanically or electrically, would cause the car to continue moving beyond its intended limits and to follow the moving chain. As a consequence the device might be damaged and/or the patient injured. Additional safety devices such as continuous limiting switches or other means are required.

e. The unit's design does not permit a patient to stop the motion of the car at any point between the foot and head of the stairs. This is a potential danger in that the patient cannot control the motion of the car to avoid objects falling in its path or persons unknowingly walking in its path. The device also precludes the return to the top or the bottom of the stairs without first going through the complete ascent and descent cycle.

f. The wheelchair platform has no provision for securing the chair during ascent and descent. The patient must depend on the wheelchair brakes to prevent the chair from rolling while it is moving on the elevator.

g. The structure is unevenly designed in that certain elements appear to be extensively overdesigned with respect to strength.

h. In general the unit is not designed economically. It would probably cost four or five times more than other commercially available devices. Although most of the others are not designed to lift the patient in his chair, the problem of transfer from the chair to the elevator seat is not formidable. Even the use of a second chair to make one available at head and foot of stairs seems to be a safer and more economical solution to this problem.

i. The use of this device would be restricted to homes which have a single flight of stairs from one level to the other without intervening landings or a platform at the foot of the stairs.

In summary, the sole special function of the unit is to permit a paraplegic or other wheelchair user to ascend and descend a flight of stairs while sitting in his wheelchair without requiring him to transfer to the elevator seat. In this respect, it is similar at least to one other commercially available home elevator for lifting both chair and occupant. The device is unsafe because the operator does not control its movement at all times. It lacks back-up safety devices. It has no provisions for securing the chair on the platform while it is being lifted. In addition, it is likely to be unnecessarily expensive due to overdesign of several sections. Even if available, the device would be restricted to homes with a single straight flight of stairs between floors without a platform on the lower end. This lengthly catalog of apparent deficiencies stems from a failure to consider the full range of patients and the variations in the environments in which the device is to be used.

2. *Revised Model Power Aid.* As previously reported (BPR 10–8) the Power Aid for wheelchairs developed by California Medical Aids, Montrose, California, was evaluated. In general, the unit was found potentially useful for several classes of patients due principally to its versatility, ease of installation, and relatively light weight. However, the evaluation brought out the need for the following modifications:

a. Improve portability by packaging it in three reasonably-sized parcels.

b. Improve the traction of the drive wheel in ascending slopes by redistributing the weight.

c. Do not ground circuit to frame.

d. Use positive-type locking electrical connectors.

e. Provide higher capacity battery charger.

f. Provide a device for uncoupling the motor from the drive wheel to permit operating the chair manually.

g. Provide means for reversing the motor to avoid rotating the tiller 180 deg.

h. Reduce force to operate the power control.

Several models of the Power Aid incorporating some of the suggested modifications were procured and subjected to a limited clinical evaluation at Rancho Los Amigos; New York VA Hospital; East Orange VA Hospital; Bronx, N.Y., VA Hospital; and the Bioengineering Research Service. For test purposes, the Power Aid was mounted on several different wheelchairs.

In general, wheelchairs equipped with a Power Aid were found to be beneficially employed by patients suffering from cerebral palsy, hemiplegia, Parkinsonism, ataxia, cardiac conditions, multiple sclerosis, certain types of triplegia and quadriplegia, and emphysema. Although several negative reactions were noted, the unit was considered quite useful on the basis of its ease of operation, versatility, and attractive appearance.

The specific positive comments were:

1. Battery easy to change.
2. Battery easily removed for folding the chair.
3. Highly maneuverable.
4. Light weight.
5. Attractive appearance.
6. Versatile application.

The following negative comments were made:

1. Control lever too hard to operate.
2. Chair moves too fast.
3. Too much power.
4. Needs clutch to facilitate manual operation or pushing by an attendant.
5. Cannot approach closely enough to or easily back away from table.
6. Loss of traction on inclines and uneven ground.

Since the initial evaluation the manufacturer has redesigned the Power Aid and furnishes it only as a unit mounted on a Howmet wheelchair with desk-type arms (Model #6488–14–15–16) (Fig. 23). The current model includes modifications which have reduced substantially the problems presented in the negative comments 1–5 above. The force required to squeeze the operating lever has been reduced. A speed control has been incorporated which permits setting of maximum speeds below the maximum available. A clutch has been incorporated which disengages the motor from the drive wheel reducing sharply the force required to propel the chair manually.

An electrical toggle switch which reverses the direction of the motor has also been incorporated. Together with the desk-type arms of the Howmet wheelchair, this permits a patient to approach a table and to back away easily. However, the vertical section of the steering post is mounted forward of the lower rail of the desk-type frame and only the side of the chair on which the Power Aid is *not* mounted can actually

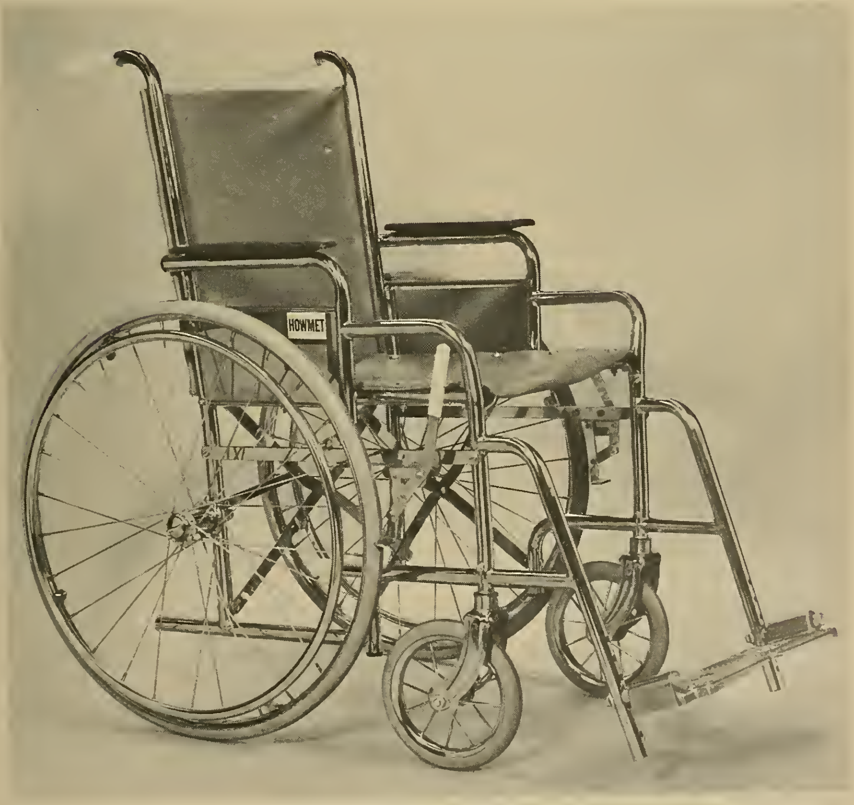


Figure 23.—The Howmet wheelchair.

be driven under a table. The patient is thus positioned obliquely with respect to the side of the table. Although the arm which controls the unit is farther away from the table, it is well within range.

Loss of traction on inclines (the sixth negative comment), may well remain a problem in special instances. Loss of traction going up hills is due to the rearward shift of the center of gravity of the entire man-chair system resulting in descreased weight on the drive wheel. At inclines above 6 deg., the loss of traction is significant and may in fact prevent ascent unless the patient leans forward in the chair as he climbs the hill. Leaning forward may reduce the problem to some degree but this form of compensation may not be available to some patients. In addition, the attempt to isolate the frame from the electrical system by insulation was inadequate leaving it still possible for a patient to receive an electrical shock.

Prescription indications for the most recent model require that the patient be capable of squeezing the manual speed control lever with a force of 5 lb. To enable a patient to steer efficiently, residual motion in the upper extremity should permit the hand to go through a range of motion corresponding to 100 deg. of internal/external humeral rotation and approximately 20 deg. of humeral flexion/extension. The new model requires that the patient be capable of operating a toggle switch at approximately the thigh level when seated. For *independent* operation, a patient must be able to reach two switches mounted on the unit at approximately ankle height (Fig. 24). However, as these switches govern motor speed and the disengagement of the motor from the wheel, they can be preset by an attendant.

The current model of the Power Aid is a substantially improved version. Two deficiencies however are still present: 1. The frame must be isolated from the electrical system. The manufacturer has accepted a suggested modification for this purpose and is currently taking steps to install the appropriate components. 2. The second deficiency relates to the location of the vertical projection of the c.g. of the entire system. It was noted in earlier models mounted on chairs other than the Howmet, that the unit lost traction on inclines due to the rearward displacement of the c.g. With the Power Aid mounted on the Howmet chair, the battery is placed farther aft than in other chairs, intensifying the problem slightly. However, the significance of this shift is best determined by more experience in patient utilization.

The Howmet wheelchair, an integral element of the system, is not presently a VA acceptable item. It was evaluated against current specifications (report in Section IV. B.4). Three deficiencies were revealed: 1. the lower end of the footrest support bar is too long (approximately 1 in.), 2. the force required to fold the chair was too high, and 3. the seat rail displaced under load to a point where it moved completely off its supporting bracket. Consultations with the manufacturer of the Howmet chair produced agreement on modifications to eliminate these deficiencies.

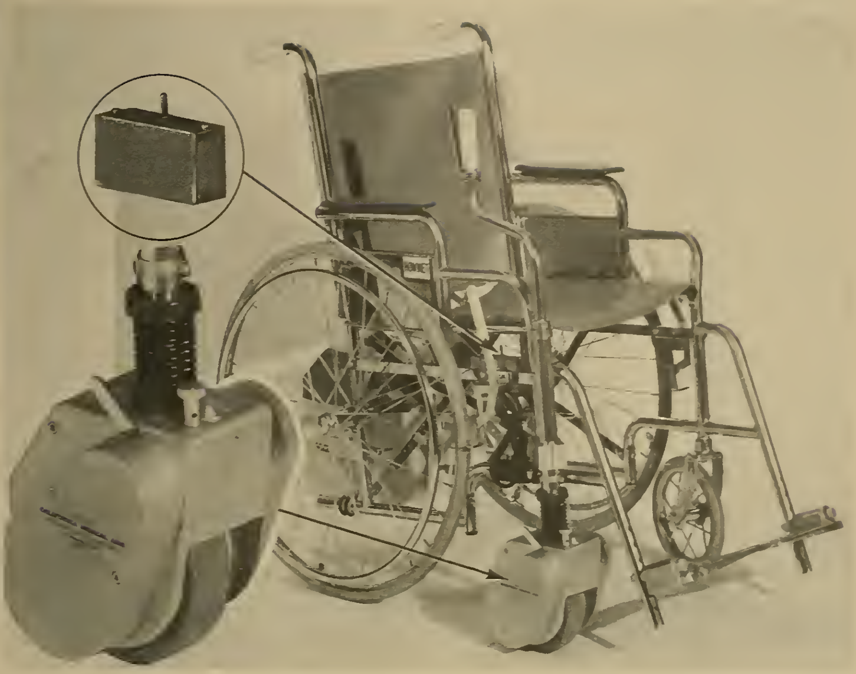


FIGURE 24.—Power Aid mounted on Howmet wheelchair. Upper inset shows switch which controls forward and backward motion. Lower inset shows lever by which drive wheel is disengaged from the motor to facilitate manual propulsion. Also shown is power control knob.

3. Wheelchair Pads. The results obtained in a limited clinical evaluation of the Stryker Floatation Pad (BPR 10–8) have stimulated interest in wheelchair pads in general. More information is needed about other commercially available wheelchair pads, the patients for whom each should be prescribed, and the time in the treatment regimen when certain pads are best utilized. Accordingly, we are continuing our limited clinical study to determine the relative value of several wheelchair cushions.

Inpatients and/or outpatients at designated VA installations, who have a history of and susceptibility to ulceration, and/or generally impoverished skin have been selected to participate. The clinic teams have chosen patients in wheelchairs who are users of a particular pad. Subjects who are "satisfied" users of, for example, the Stryker Pad or the "Bye Bye" Decubiti Pad, have been issued another pad. At the time of delivery, a preliminary questionnaire designed to elicit pertinent facts about time and use of wheelchairs and wheelchair pads was administered by the clinic team. After 1-month, 2-month, and 3-month periods, follow-up questionnaires are being administered by the clinic team. This information will provide data for the final report.

4. Howmet Wheelchair. A Howmet wheelchair of recent design, manufactured by the Howmet Corporation Hospital Division of Archbold, Ohio, was evaluated for compliance with current standards for wheelchairs (Fig. 23).

Deviations from standards are recorded below in accordance to their specification numerical listing.

Specification Requirements	*Deviations*
Leg rest Length (3.2.2)—The lowest point of the footplate to be at least 2½ in. from floor surface.	1¾ in.
Wheels (3.2.3.2)—Chairs equipped with 24 in. diameter drive wheels should weigh no more than 45 lb.	23⅞ in. diameter drive wheels with the chair's weight being 46 lb.
Dust Cap (3.2.3.2)—To be provided.	None provided, but the flanged hub may have been intended to serve as such.
Tires, Solid (3.2.3.2)—Compressibility at least 1 in. under a 200-lb. load.	¾ in.
Comfort (3.2.5.2)—With an occupant, gapping between seat and backrest should be no more than 1 in.	1⅞ in.
Comfort (3.2.5.2)—The chair shall provide some means to prevent occupant's feet from sliding off footplate.	No provision.
Ease of Operation (3.2.5.4)—The force to fold chair with one hand shall not exceed 15 lb.	25 lb.
Instructions (4.0)—Illustrations, operation, and care to be provided.	Attached tags describe nominal service operation.

Noted during durability tests was rearward deflection of the dual cross-frame members which prevented the seat rails from properly engaging their respective support brackets.

The deviations from the standards have been brought to the attention of the manufacturer.

C. Evaluation (Techniques)

None.

V. TESTING

A. Standards Development Program

1. Elastic Hosiery. In a previous issue (BPR 10–8, pp. 208–210), we described our efforts to develop adequately objective methods and instruments for measuring the compression forces applied to the lower limb by elastic hosiery. We pointed out that there was extreme variability in both the magnitude and the pressure gradients applied by stock samples of commercial elastic hosiery as measured by the Circumferential Tension

Approximation Method (CTAM) developed at the VA Prosthetics Center and described in BPR 10–6. Moreover, by this method we could not replicate the compression patterns described by manufacturers of custom elastic hosiery.

During the present reporting period, two new methods for measuring the compression forces applied by elastic hosiery have been tested. The first employs an electronic pressure transducer (VAPC Sensotec) consisting of a metal capsule 0.5 mm. thick and 6.35 mm. in diameter described in detail in Section I.A.1. The pressure transducer was placed directly on the lower extremity at a point 3 in. from the floor and the elastic stocking was carefully donned to avoid displacing the instrument. Pressure was recorded at this level and subsequently at points 1 in. apart above the malleoli up to the top of the stocking (Fig. 25). Shown in Figure 26, are the results of measuring the compression applied by a custom elastic stocking and a stock one-way stretch elastic stocking both of which were specifically ordered for the same subject. In general, higher pressures were recorded by the electronic transducer than previously by the CTAM. From a point approximately 10 in. above the ground to the top of each stocking, a desirable negative gradient was recorded for both the custom and stock hose. The pressure drop over his region was approximately 25 mm. Hg. or ½ lb./in. ^{2}. However, in the region between the malleoli and the mid-calf, undesirable positive gradients were recorded with pressure increasing approximately 25 mm. Hg. from the malleoli to the mid-calf.

The second method employed the "Komprit Compression Tester," a German product designed specifically for measuring the compression of elastic hosiery. It consisted of a rubber bag which is placed beneath the sock and a microswitch located outside the sock directly over the bag (Fig. 27). When air is pumped into the bag it deflects outward. This deflection is sensed by the microswitch which causes a light to go on and a buzzer to sound. At this signal the manometer on the tester indicating the hose compression is read.

When measured by this instrument, both the custom and the one-way stretch hose appeared to apply a neutral pressure gradient from 6 in. above the floor to the top of the sock (Fig. 28). (Below 6 in., the contour of the leg precluded the use of the Komprit; in order to obtain an accurate measure, the surface has to be relatively flat.) The magnitude of pressure was approximately 40 to 50 mm. Hg.

Three significantly different pressure readings were obtained by the three test methods applied. Of the three, the electronic method seems to be the most accurate and reliable.

2. *Comparative Analysis of Eight Wheelchairs.* In continuation of our program to develop functional specifications for wheelchairs, a large scale field evaluation program was completed. To control the quality of the

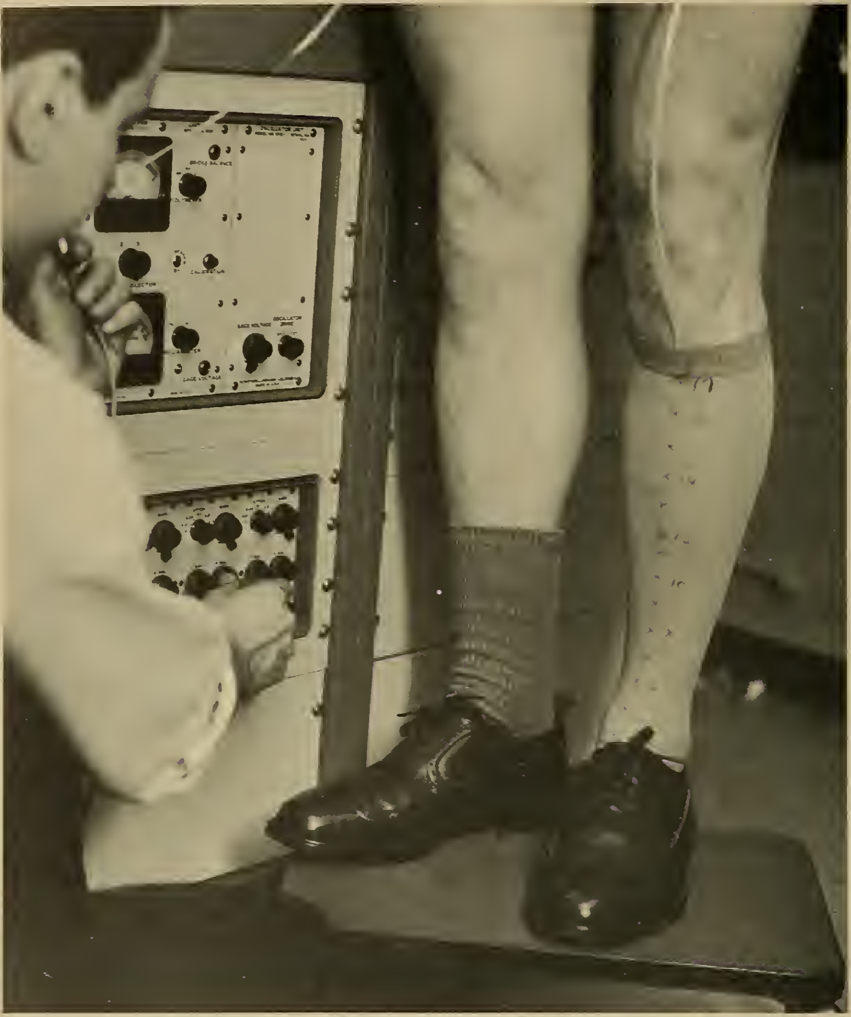


FIGURE 25.—VAPC-Sensotec pressure transducer used to measure pressure applied by elastic hosiery.

80 chairs (10 chairs each of 8 types) a physical inspection of each chair was performed prior to shipment to participating clinics. In addition one sample of each type (8 chairs) was checked against the complete range of tentative VA functional specifications. A test program for physical evaluation in the field was also developed together with appropriate equipment and instruments. The results of these tests will be reported in a future issue of the Bulletin.

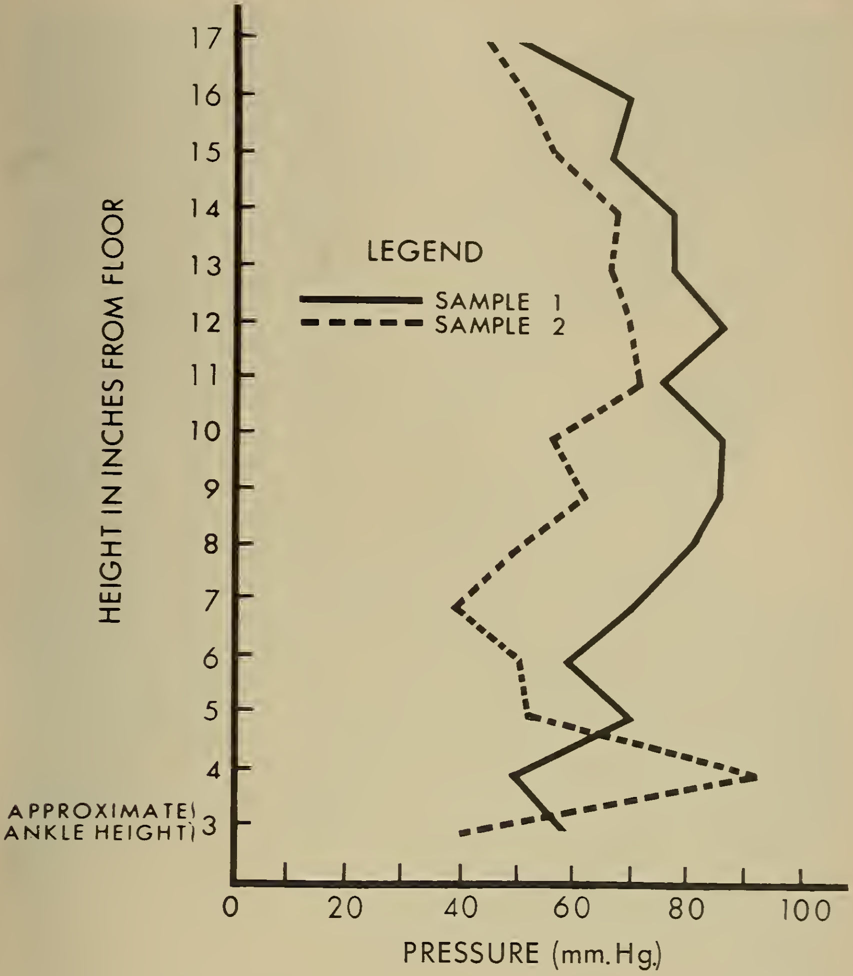


FIGURE 26.—Pressures applied by two types of elastic hosiery as measured electronically. Sample 1—custom elastic hosiery; sample 2—stock one-way stretch elastic hosiery.

B. Compliance Testing

1. Stump Socks

Knit Rite Post-Operative Stump Socks. Two samples of stump socks designed especially for immediate postsurgical application were evaluated against appropriate VA standards for stump socks and to determine compression characteristics. These tests were applied as a first step in our effort to develop standards for stump socks used in postsurgical prosthetics management.

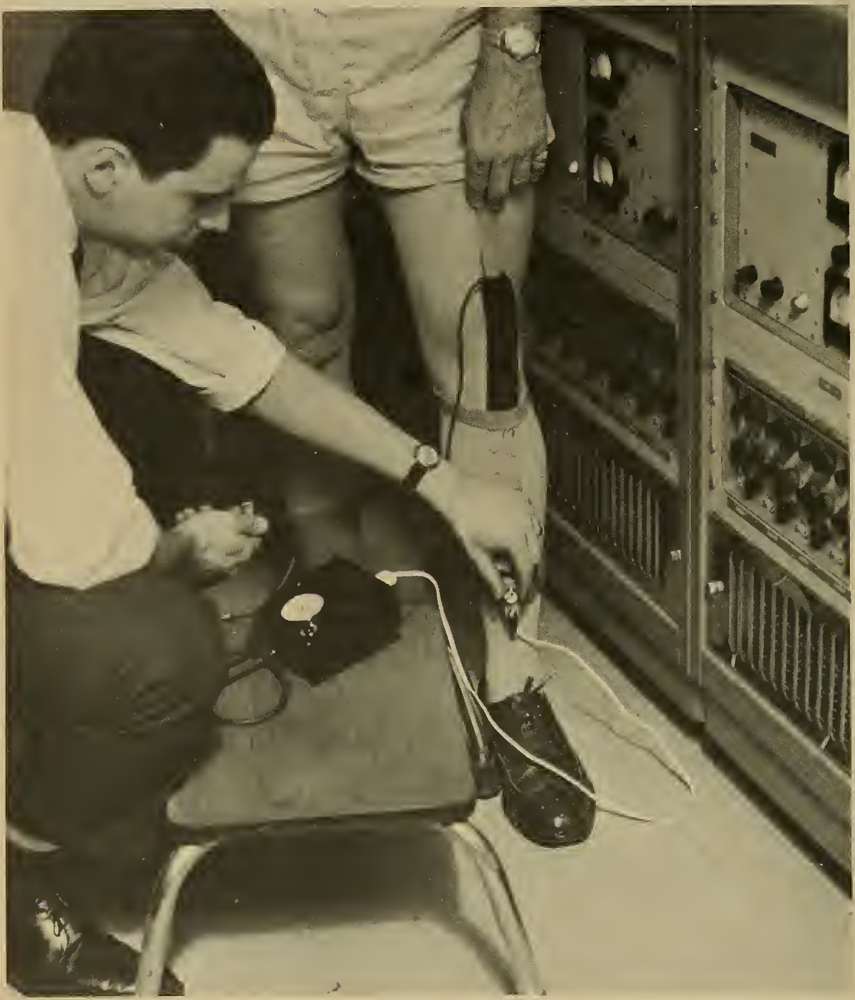


Figure 27.—"Komprit" pneumatic pressure meter used to measure pressure applied by elastic hosiery.

Both samples shrank excessively at a point 2 in. from the distal end and one sample in addition shrank excessively at a point 6 in. from the distal end. The fabric content of both samples is Orlon-acrylic fiber (95.25 percent) and Lycra-Spandex fiber (4.75 percent); thus, it is questionable whether these standards designed for 100 percent wool socks could be applied. Moreover, this type of stump sock is currently used in a one-time application in immediate postsurgical fitting. Its shrinkage therefore, after five washing cycles, is of less consequence than as in wool stump socks designed for continuous use.

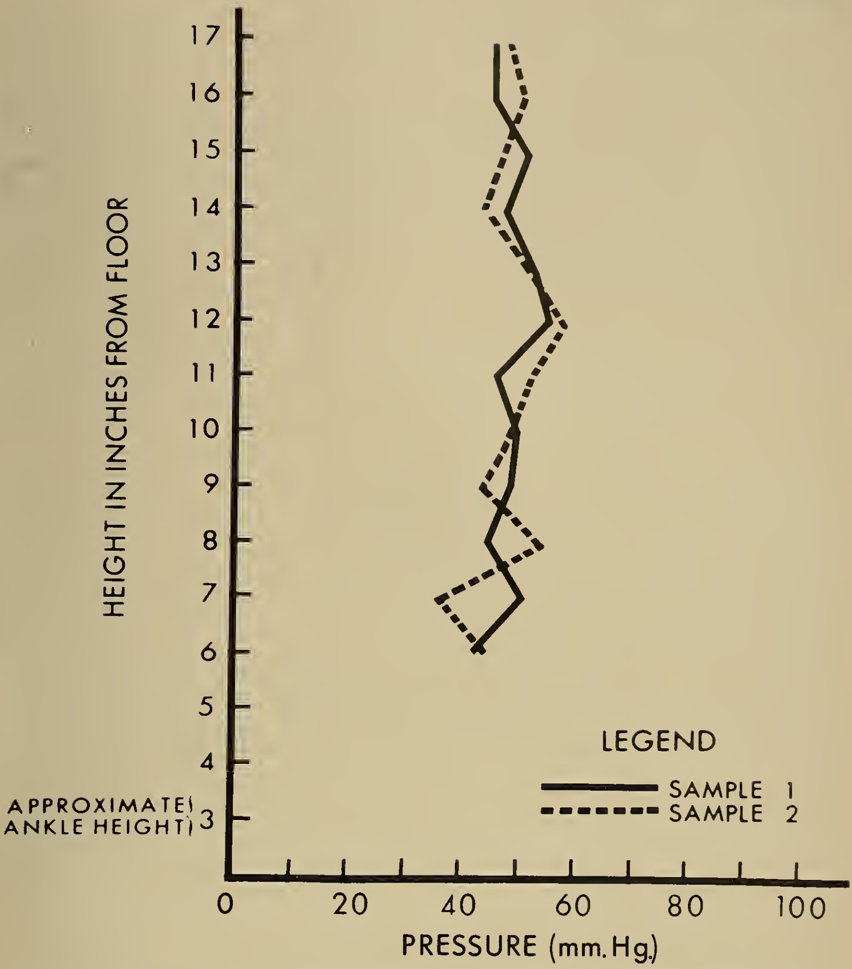


Figure 28.—Pressures applied by two types of elastic hosiery as measured pneumatically. Sample 1—custom elastic hosiery; sample 2—stock one-way stretch elastic hosiery.

Compression forces exerted by these socks are being measured by means of the VAPC-Sensotec pressure transducer.

2. *Upper-Extremity Components*

a. APRL #44 Voluntary Closing Hand. One model of the APRL #44 hand was checked for compliance with the Tentative Specifications for "Hands, Adult Size, Voluntary Closing." This terminal device, manufactured by the Sierra Engineering Company and distributed by the A. J. Hosmer Corporation, generally conformed to specification requirements. The force required to move the active fingers through their complete range was marginally adequate however, ranging between 7 and 9.5 lb. The requirement is 6 to 8.5 lb.

b. APRL Voluntary Closing Hook. One model of the APRL hook manufactured by the Sierra Engineering Company and distributed by the A. J. Hosmer Corporation failed to meet currently applied specifications in that excessive force to close the fingers was required to obtain a secure grasp between the fingers (functional requirement III.B.5). The distributor has been apprised of the deficiency.

3. SACH Feet. During this period, four manufacturers submitted samples of SACH feet for annual compliance testing. The results of the tests indicated that three manufacturers' products were in substantial compliance with the requirements. The other sample could not be rated as acceptable in view of two significant deviations from the specification requirements: a. toe-break too short and b. toe-curl in excess of allowable limits.

In addition, samples of a new SACH foot were submitted by the Navy Prosthetics Research Laboratory for evaluation. The foot is constructed of a laminated wood keel and a molded sole and toe section. The unit was tested by comparison with applicable standards for SACH-type feet (VA Specifications No. VAPC–L–5902–3).

With two minor exceptions the foot met all the functional requirements set forth in the specifications. Toe-break fell short of specifications—feet marked size 13 were actually size 12 and the A and B reference lines were not indicated. The discrepancies were of very small magnitude and, apprised of them, the developer will have little difficulty in modifying them to meet requirements. At the present time these feet are not commercially available, but we are informed by the developer that arrangements are being made for commercial fabrication.

VI. OPERATIONS REPORT FOR FIRST HALF, FISCAL YEAR 1968

The VA Prosthetics Center experienced a significant increase in activity in the 6 months ending December, 1967, when "services rendered" totaled 44,459 as compared with all of Fiscal Year 1967, ending June 30, 1967, when total services provided (for the full year) were 63,821. Issues of new orthopedic shoes and shoe repairs were increased (Table 3). The use of temporary prostheses increased somewhat, as did the production of permanent prostheses, as reflected in Tables 5, 6, and 7. In all probability, the increases were due to the influx of wounded veterans from the Vietnam era and the increasing frequency of disabilities of age associated with veterans of World War II and the Korean conflict.

The data reflected in the following pertain to major services rendered veteran beneficiaries, during the first half of Fiscal Year 1968, by the VA Prosthetics Center's Orthopedic Shoe Service, Prosthetics-Orthotics Service, and the Restorations Service. In most instances fiscal year comparisons are included.

A. The Orthopedic Shoe Service

Table 3 reflects full year fiscal comparisons of our national Orthopedic Shoe Program from 1964 through 1967 and including the first half of Fiscal Year 1968. We experienced an increase of 123 beneficiaries for the first half of Fiscal Year 1968. In addition we provided 159 veterans with ortho-inlay shoes, at a savings in excess of $7,000. We also issued 50 pairs of overshoes and rubbers.

TABLE 3.—*VAPC National Orthopedic Shoe Program*

	Fiscal year				
	1964	1965	1966	1967	First half 1968
Beneficiaries on rolls	10, 021	10, 322	10, 587	10, 861	10, 984
New shoes, prs.	7, 317	7, 336	7, 688	7, 181	3, 789
Prs. of new shoes issued per benef. on rolls per yr.	. 73	. 71	. 73	. 66	[a]. 69
Repaired shoes, prs.	9, 484	9, 422	10, 432	8, 932	4, 963
Prs. of shoes repaired per benef. on rolls per yr.	. 95	. 91	. 99	. 82	[a]. 90

[a] Projected for full fiscal year.

B. The Prosthetics-Orthotics Service

Table 4 reflects the activity in the Orthotic Components Unit of the Prefabricated Appliances Section relating to the distribution of surgical supports and elastic hosiery. Table 5 reflects a distribution of prosthetic components. In addition 8 cervical collars and 12 Knight spinal braces were distributed.

The Limb and Brace Section of the Prosthetics-Orthotics Service fabricated and delivered lower-extremity prostheses and braces as indicated in Tables 6, 7, and 8. Other items fitted are as follows: Arch Supports, 825; Artificial Arms, 17.

TABLE 4.—*VAPC Surgical Support and Elastic Hosiery Programs*

Issuance channel	F.Y. 1964		F.Y. 1965		F.Y. 1966		F.Y. 1967		First half F.Y. 1968	
	Surg. supp., ea.	Elas. hos., ea.	Surg. supp., ea.	Elas. hos., ea.	Surg. supp., ea.	Elas. hos., ea.	Surg. supp., ea.	Elas. hos., ea.	Surg. supp., ea.	Elas. hos., ea.
Directly to veterans	2, 434	9, 989	2, 482	9, 554	2, 634	9, 801	2, 697	10, 866	1, 145	5, 591
VA Orthopedic Shops	3, 995	12, 258	3, 722	11, 049	5, 885	14, 517	5, 056	15, 924	2, 243	7, 708
Totals	6, 429	22, 247	6, 204	20, 603	8, 519	24, 318	7, 753	26, 790	3, 388	13, 299

TABLE 5.—*Distribution of Prosthetic Components by VAPC, First Half F.Y.* 1968

Issuance channel	Temporary prostheses [a]			SACH feet	Hydraulic systems [b]			
	AK	BK	Total		Initial issue	Replacement issue	Total	Active wearers [c]
For specific beneficiaries	42	64	106	76	223	603	826	2287
VA Orthopedic Shops	51	63	114	172	—	—	—	—
Totals	93	127	220	248	223	603	826	2287

[a] In F.Y. 1967 we distributed 151 above-knee temporary prostheses and 212 below-knee prostheses respectively.

[b] In F.Y. 1967 we had 2081 active wearers of hydraulic systems.

[c] Seventeen wearers changed from one hydraulic system to another hydraulic system or were issued spares.

TABLE 6.—*Complete Below-Knee Artificial Limbs Fitted by VAPC, First Half F.Y. 1968*

Type	Permanent	Temporary	Total
PTB			
Cuff	14	4	18
Lacer	6	4	10
Carved wood	8	—	8
Molded socket, non-PTB	23	6	29
Syme	10	—	10
Chopart	1	—	1
Totals	62	14	[a] 76

[a] 150 below-knee artificial limbs were fitted in F.Y. 1967.

TABLE 7.—*Complete Above-Knee Artificial Limbs Fitted by VAPC, First Half F.Y. 1968*

Type	Permanent	Temporary	Totals
Molded socket, non-total contact	17	8	25
Molded socket, total contact	29	16	45
Carved wood socket	6	—	6
Hip disarticulation	7	—	7
Knee bearing	4	—	4
Totals	63	24	[a] 87

[a] 153 above-knee artificial limbs were fitted in F.Y. 1967.

TABLE 8.—*Braces Fitted by VAPC, First Half F.Y. 1968*

Item	Number
Below knee	73
Above knee	46
Arm	3
Spinal, prefabricated but custom fitted	52
Cervical collars	14
Total	[a]188

[a] In F.Y. 1967, 539 braces were fitted.

C. The Restorations Service

Table 9 reflects the activity of the Restorations Service in its major prosthetics responsibilities.

TABLE 9.—*VAPC Production of Restoration Items, First Half F.Y. 1968*

Item	Number
Artificial eyes	176
Body restorations	21
Cosmetic gloves	28
Facial restorations, ear	2
Facial restorations, nose	3
Facial restorations, orbital	4
Plastic hands, full	12
Plastic hands, partial	10
Tinting of gloves	6
Repairs to appliances (all)	14
Other items or services	82

D. Special Clinic Team

The Special Clinic Team met 23 times during this period. Sixty veterans were referred by 19 VA field stations.

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NOTE: This report was prepared by Dr. Edward Peizer with the assistance of Donald W. Wright, Henry F. Gardner, William J. McIlmurray, and James Cohen.

HIGHLIGHTS OF OTHER VA RESEARCH PROGRAMS

PROSTHETICS

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John O. Esslinger, M.D.
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In February 1968, a manuscript was submitted for publication in *Orthopaedics and Related Research* covering the years since 1952 when the project on "semi-buried implants for the attachment of external prostheses" was conceived.

Two new studies began on the modified Teflon bone plug, and they are presently being followed. Some personnel from the Metallurgy Department of the Ford Motor Company were met with to discuss the development of a procedure which would make it possible to examine soft tissue in which Vitallium wire screening had been inbedded. Since Vitallium is such a hard metal it was necessary to mount the specimens in epoxy resins. This will hopefully enable the people at Ford to obtain sections using their diamond knife microtome. The sections will then be stained and photomicrographs obtained.

Gilmatic, Northridge, California
Gilbert M. Motis

Major activities have concerned the Solenoid elbow lock and its switch involvements. Now a "pad" type switch is available which may be placed into the socket for muscle operation. Because of its construction, it is not necessary to alter the socket in any way. The switch may be installed on a trial basis in the area of the biceps muscle and moved about until the operating results are satisfactory to the amputee.

The switch operates a relay delay system so that continuous switch contact adjusts the system to a low current drain to save battery consumption. A battery charger, also a part of the system, permits the amputee to "plug-in" at night to restore the battery. A complete unit was sent to the Bioengineering Research Service of the VA Prosthetics Center for evaluation.

The "Extendo-flex" unit is now being machined for tests on three amputees and will be available soon.

A motor-driven elbow unit is now in process to provide two field test models. These will duplicate the bench model which was successful on all load and current drain tests.

Mauch Laboratories, Inc., Dayton, Ohio
Hans A. Mauch

The clinical tests of the Swing and Stance Control System for above-knee amputees have been continued with generally favorable results. The causes for the oil contamination revealed in these tests were isolated, and remedies were found. A recirculation program for the correction of the systems involved was started in November 1967 and is 60 percent complete.

In preparation for the first production run of the Swing and Stance Control System, an effort is underway to eliminate whatever minor shortcoming have become known from the clinical tests and from other systems returned to the developer for checkups.

A wooden setup for this hydraulic knee system, which comes closer to established commercial designs than the present setup and which is still strong enough for the high stresses encountered with a stance control system, has been developed. It employs a modified geometry for the kinematics of the hydraulic system which will provide a number of benefits for the dynamics of walking and stair descent. It will also permit shortening of the hydraulic system by 1 in. which improves cosmesis of the shank. Amputee testing of one prototype has been underway since January 1968 with very good results. The expected benefits have been confirmed. Two setups with shortened hydraulic systems will be shipped to the Veterans Administration in New York for additional testing in April 1968.

All the preliminary work for the production prototype Hydraulic Ankle was completed in December 1967. Trial assemblies and bench tests indicated that all principal design goals have been achieved. Amputee tests carried out in January 1968 had very satisfactory results, but additional bench tests and investigations revealed the need for further improvements, particularly regarding better toe-slap damping and speedier return of the plantar-flexed foot after toe-off. A number of design changes were introduced and tested during February and March with generally satisfactory results. It appears now that parts for shakedown test units can be ordered at the end of April or the beginning of May 1968.

National Academy of Sciences-National Research Council
Washington, D.C.
Herbert Elftman, Ph. D.

During the period from September 1, 1967, through March 31, 1968, the Committee on Prosthetics Research and Development continued to advise and assist in the coordination of prosthetics and orthotics research sponsored by both governmental and private agencies. At the request of the sponsoring agencies concerned, the Committee made specific recommendations on 29 proposals for research and development projects and conducted three site visits.

Major activities were:

CPRD Meeting

The seventeenth meeting of the Committee was held at the National Academy of Sciences, Washington, D.C., on October 21, 1967. All members and two past members were present. Liaison representatives from the Children's Bureau, the Social and Rehabilitation Service, and the Veterans Administration participated in the meeting. The work of the previous year was reviewed in detail, and recommendations for future activities were made. A comprehensive report was prepared, and 37 copies were distributed.

Workshop on the Human Foot and Ankle

In keeping with its major purpose of renewing familiarity with work that has been done in basic research and stimulating investigations in areas where knowledge is limited or lacking, the Subcommittee on Fundamental Studies conducted a Workshop on the Human Foot and Ankle in Boston, Mass., March 1–2, 1968. There were some 30 participants. It was hoped that the workshop, the first to be sponsored by the recently established Subcommittee on Fundamental Studies, would set a pattern for other workshops to follow. Hoped-for outcomes of such workshops are documents calling attention to gaps in present knowledge and delineating specific problems where research is required. At the workshop in Boston, major presentations were made on the Mechanical Properties of Cartilage, the Biomechanics of the Foot and Ankle, and the Influence of the Foot-Ankle Complex on the Proximal Skeletal Structure. Three adult and three child cases were considered and discussed in detail. In addition, consideration was given to a method of treating tibial fractures by the application of a cast permitting freedom of motion.

Subcommittee on Design and Development

The seventh meeting of the Subcommittee on Design and Development was held in Washington, D.C., on October 20, 1967. The work of the various panels sponsored by the Subcommittee was reviewed. It was thought that it would be desirable to hold future meetings of the Subcommittee at least three or four times per year, at major research and development centers.

Panel on Lower-Extremity Prosthetics Fitting

The Panel on Lower-Extremity Prosthetics Fitting held its seventh meeting at Rancho Los Amigos on January 6, 1968. Major topics considered were air-cushion sockets, patellar-tendon supracondylar sockets. Münster below-knee sockets, pressure studies, alignment studies, fluid-lined sockets, the direct forming of sockets, transparent sockets, and the fitting of knee-disarticulation cases. Informal commitments were made by individual panelists to carry on further work with specific items.

Panel on Lower-Extremity Prosthetics Components

The Panel on Lower-Extremity Prosthetics Components held its third meeting in Miami Beach, Fla., December 17, 1967. Major topics considered by the panelists were foot-ankle units, torque absorption units, modular construction, components for immediate postsurgical fitting, cosmetic covers, knee devices, prostheses for hip-disarticulation and hemipelvectomy cases, and the "get it into production" problem.

International Activities

At its meeting during October 1967, the Committee on Prosthetics Research and Development decided to participate with the Veterans Administration and the Social and Rehabilitation Service in organizing an exhibit for the XI World Conference of the International Society for Rehabilitation of the Disabled to be held in Dublin during 1969.

At the request of the Social and Rehabilitation Service, the Assistant Executive Director departed from the United States on March 17, 1968, to participate for some 6 weeks in a prosthetics evaluation study in Yugoslavia. Following this, he will visit prosthetics research and development centers in Poland, Germany, and the United Kingdom.

Prosthetics and Orthotics

Prosthetics and Orthotics, the report of a Conference held under the sponsorship of the Committee on Prosthetics Research and Development during December 1966, appeared as an unnumbered National Academy of Sciences publication during 1967. This 41-page publication has had to be reprinted because of widespread demand. The Conference reported on was held at the request of the Vocational Rehabilitation Administration for the purpose of developing information for use in planning research and development activities in prosthetics and orthotics for the next 5 years and longer.

Artificial Limbs

The Autumn 1966 issue of the Journal *Artificial Limbs* was distributed during October 1967, and the Spring 1967 issue was distributed during March 1968. The manuscript for the Autumn 1967 issue was sent to the printer during March 1968. Material for the Spring 1968 issue is being assembled.

The Spring 1967 issue contains an article entitled "Limb Prosthetics—1967" by the Executive Director. This article is an updated version of "Limb Prosthetics Today" which appeared originally in *Artificial Limbs* for Autumn 1963. This article was reprinted in *Physical Therapy* and in the Danish *Journal of Physical Therapy,* soon after it appeared in *Artificial Limbs,* and the printers of *Artificial Limbs* received orders for about 15,000 reprints. Orders for more than 10,000 copies of the reprint of the revised version have already been given by the prosthetics schools, the American Orthotic and Prosthetic Association, and the Committee on Prosthetic-Orthotic Education.

Demonstration

The staff of the Committee on Prosthetics Research and Development arranged for a demonstration of the fabrication of transparent experimental sockets for research groups interested in such a technique. The demonstration was conducted by personnel of the Army Medical Biomechanical Research Laboratory who developed the method.

Visit to the University of Utah

At the request of the Advanced Research Projects Agency's project at the University of Utah, an *ad hoc* committee visited the group on February 27, 1968, in order to advise them concerning the application of newly developed computer techniques in prosthetics and orthotics research and development.

Liaison with AEC

Liaison was effected with the Atomic Energy Commission, who requested assistance in finding new uses for a recently developed steel with unusual qualities. Engineering drawings of parts that might be improved by use of the new steel were forwarded to the AEC for fabrication of parts for testing. One set of parts is now being tested.

Thermography

The CPRD made arrangements for two groups of research personnel to visit Barnes Engineering Corporation, Stamford, Conn., to explore the feasibility of employing special heat-measuring equipment (Barnes Thermograph) in prosthetics and orthotics research.

Report from Yugoslavia

The Executive Director assisted in the editorial work for "External Control of Human Extremities," a report of an international symposium sponsored by the Yugoslav Committee for Electronics and Automation held in 1966, and published under the International Program of SRS.

New York University, New York

Renato Contini

A program of test socket modifications has been instituted. The initial phase of this program consisted of permanent modification to the brim of two sockets in an effort to measure brim pressure as a function of contour. The medial region of the brims was built up approximately $1/16$ in. This area was chosen since one subject consistently produces high pressures on the ramus (30 to 50 p.s.i.) while those of a second subject are relatively low (below 10 p.s.i.). Apparently this modification had no large effect on the pressures, local or otherwise. The baseline data used for comparison had been collected some weeks earlier.

The fabrication of a series of removable contoured shims is planned. These shims will be designed to fit over the original brim and will blend into adjacent areas so as to present smooth and unbroken surfaces to the stump tissue. The shims will permit the comparison of pressure data resulting from several configurations. These data will be collected during the same test period rather than several consecutive days or weeks. (Variations in pressure on a daily, weekly, and monthly basis were discussed in the preliminary report on this study, published in BPR 10–8 Fall 1967.)

A modification to the distal end of one socket is about to be tested. The extent of the modification was determined by injecting a foam-in-place Silicone rubber through the valve insert. The result is a cast of the excess space or relief provided at the distal end of the socket. This soft cast has been duplicated using a hard casting epoxy. This removable duplicate will be smoothed and blended into the socket walls. Duplicate tests will be run on the same day to determine the effects of this modification.

A series of bench tests have shown that the transducers being used are sensitive only to pressures or forces which act perpendicular to the face of the diaphragm, or the piston. Shear or slippage at and parallel to the socket wall has no effect on the outputs of the transducers. The output of the transducer with the flush diaphragm varies markedly when sampling a large or discontinuous pressure gradient. Since the stumps of above-knee amputees are fleshy, there is no reason to question the data obtained with these units.

Northwestern University, Chicago, Illinois
Robert G. Thompson, M.D.

Electric Power Assist Unit

This unit, designed to be used with a body-powered above-elbow, shoulder-disarticulation or forequarter prosthesis, is complete in itself and is attached to an existing prosthesis and control (harnessing) system.

A Model II unit, which was fitted to an 18-year-old male, forequarter amputee, is used to externally power the prosthesis rather than serve as a power assist because of the difficulty the amputee has in obtaining 70 deg. of flexion with body power. The amputee has been wearing the unit for 20 months with excellent function and control. The only problem to arise was premature battery failure due to a defective cell. Efforts to evaluate this unit on other amputees during this past year were unsuccessful. Of the four patients who were suitable candidates for the unit, two expired before fitting and two declined fitting. Two units are available for evaluation by interested centers.

Powered Hand Splint

A quadriplegic has been using a hand splint powered by an electric power assist unit for 10 months. Pinch force is approximately 4 lb. The drive mechanism and battery are contained in an aluminum case 1½ in. x 2 in. x 10 in. in size which is mounted to the wheelchair. The unit is controlled by switches operated by the opposite arm.

In attempting to utilize the AMBRL two-level switch it was found that the available control motions interfered with the limited body motions that the patient used for everyday activities. It appears that the switches operated by the opposite arm is the best method of control inasmuch as the patient is able to accomplish most grasping tasks without aid from the hand used to operate the switches.

A second unit has been constructed using a less expensive motor and simplified drive mechanism. This unit is to be installed on a new patient when he receives his splint.

Powered Wrist Rotator

This wrist unit, capable of pronation and supination, is simple in design, weighs 9 oz. and is laminated to the end of the forearm of a prosthesis in a manner similar to a standard wrist unit. The unit was fitted to a bilateral below-elbow amputee who controlled it by an AMBRL two-level switch mounted on a chest strap. After about 15 minutes of practice the amputee had good control of the unit.

Two units have been constructed, for a bilateral below-elbow amputee and a bilateral above-elbow amputee. However, noise is a major problem and will have to be diminished before the units are fitted to the amputees.

Powered Wrist Rotator/Terminal Device

The preliminary design for a combination electrically powered wrist rotator and terminal device has been completed. This unit will give powered supination, pronation, and prehension.

Ball and Socket Shoulder Joint

A small testing machine has been designed to measure the dynamic and static coefficients of friction of various combinations of materials suitable for use in a shoulder joint. This information will be useful in instances where friction is desired and the "stick-slip" phenomenon is a deterrent to good function. This project is continued on a low priority basis.

EMG Signal Processor

This processor incorporates Bottomley's concept of "autogenic backlash." It processes the EMG signal into an extremely low ripple analog signal which is related to EMG activity but which maintains a rapid dynamic response. The stability of this electrical signal enables it to be used in proportional systems, logic networks, position control systems, and any other analog system using electrical inputs of between ±9 volts. This unit has been miniaturized for mounting directly on the body. It is planned that this unit will be a basic module in various myoelectric systems.

Wheelchair Speed Controller

A speed controller which is at least 93 percent efficient has been developed to power the standard electric wheelchair. This unit uses pulse-width modulation of the motor armature current to achieve efficient speed control. The unit operates at 12 volts and supplies 40 amperes of current when the chair is stalled.

The unit has been tested temporarily on a chair and is intended for use on a head-operated chair. The speed controller has also been operated by myoelectricity.

Three-Mode Controller

A three-mode controller (one set of electrodes) has been developed for prosthetic and orthotic use. The design of this controller is based upon the ideas of Scott at New Brunswick University. However, several modifications have been made. A null space has been inserted between the two active modes of control. Also, the unit is less susceptible to noise since the mode initiated by intermediate EMG signals operates only when the zone is entered by a signal which is decreasing. This controller is currently being tested on a quadriplegic patient. Proportional control using pulse-width modulation has also been added to the basic three-mode controller and three different variations of the three-mode device are currently under investigation.

Seven-Mode Controller

A seven-mode controller which uses two sets of electrodes has been successfully demonstrated in the laboratory. This controller is not difficult to operate and the device could give a high level amputee easy control of hand opening-closing, supination-pronation, and elbow flexion-extension. A simple nudge switch could be used to obtain six additional control modes. The system is now being evaluated.

Pierced Skin Technique for Electrodes

Wire electrodes are looped through tunnels in the skin in much the same manner that earrings are inserted through pierced ear lobes. The idea is to achieve a definite mechanical linkage to the body and at the same time develop electrical contact. Two of these electrodes have been inserted in a subject but preliminary results were not encouraging.

Above-Knee Pneumatic Sockets

One above-knee amputee continues to wear the above-knee prosthesis with the inflatable air bag incorporated into the lateral wall of the socket. However, because of the satisfactory fit of the socket initially and relatively constant stump volume the amputee has not used the air bag.

An above-knee suction socket was constructed in which the lateral wall was rigid for support of the femur, and a Silastic inflatable liner encompassing approximately three-fourths of the area of the stump was incorporated into the remainder. Due to the negative pressure produced in the distal socket during swing phase, air is introduced into the air chamber of the socket through an intake check valve. During stance phase, the pressure against the stump produced by the inflated area is controlled by expulsion of air through a secondary adjustable check valve into a reservoir chamber. Because of the automatic pumping action at every step, constant controlled pressure can be maintained and an air tight seal at the junction of the Silastic and the polyester is not imperative.

One amputee has been wearing the socket on a very limited basis. An extended trial period will be necessary before any conclusions can be reported.

Below-Knee Sockets

Four below-knee amputees have been fitted with PTS prostheses: two hard sockets and two with soft inserts. In our limited experience, the sockets with the soft inserts allowed easier entry of the stump into the socket.

Two of the amputees who were fitted with PTS prostheses requested modification to PTB prostheses. The amputee with the soft socket disliked the restriction of the quadriceps tendon which prohibited full extension of the shank. In the case of the amputee with the hard socket, the prosthesis was found too difficult to don.

A bilateral below-knee amputee was fitted with PTS prostheses but due to considerable intermittent volume change in the stump on the newly amputated side and because of lack of sensation at the distal end of the stump the amputee experienced recurrent stump breakdown; therefore, it was necessary for the amputee to be fitted with a conventional PTB prosthesis with hinges and thigh corset.

Thermoplastic polymer rubber material was tested as a means of direct forming of below-knee sockets. Two methods were investigated: 1. direct forming against the stump and 2. direct forming against a model of the stump. The thermoplastic material requires reinforcement. Direct application of polyester resin to the thermoplastic material on the stump caused no skin irritation; however, the resin fumes caused some discomfort.

Immediate Postsurgical Fittings

During the 12-month period of April 1, 1967 through March 31, 1968, 26 immediate postsurgical fittings have been carried out: 15 below-knee, 10 above-knee, and 1 Syme's.

Three methods for constructing the above-knee brim have been studied: 1. prefabricated plastic brim, 2. prefabricated plaster brim, and 3. molding of the plaster brim using the PRS above-knee casting jig.

Studies on improving suspension methods for above-knee immediate postsurgical fittings is continuing.

Since the below-knee procedure of immediate postsurgical fittings is fairly well standardized, this Center is beginning to phase out of the below-knee program as a research item; however, we are continuing to serve, on a consulting basis, the Veterans Administration Research Hospital or other facilities who request our assistance.

Early Postsurgical Fittings

Three early postsurgical fittings have been accomplished: 1 quadrilateral amputee (bilateral below-elbow, bilateral below-knee), 1 bilateral amputee (right below-knee, left Chopart), and 1 unilateral below-knee amputee. The quadrilateral amputee's below-elbow stumps were fitted with plaster sockets incorporating terminal devices. The below-knee stump of the bilateral amputee and the unilateral below-knee amputee were fitted with plaster sockets with pylon and foot attached. The temporary prostheses allowed the amputees to begin early prosthetic training during the interim of definitive fitting. In all instances significant stump shrinkage was evidenced within two days of fittings.

Polycentric Knee

Production engineering of the polycentric knee sponsored by the Veterans Administration is nearly completed. Approximately 25 models will be produced for distribution to various centers for evaluation.

Thigh Kicker for Hip-Disarticulation and Hemipelvectomy Prostheses

To initiate flexion of the thigh immediately following toe-off a torque around the hip joint is produced by compression of a spring between the socket and the thigh from heel strike to mid-stance. A Northwestern University polycentric knee prevents this torque from causing the knee to buckle prior to foot-flat. Initiation of thigh flexion prior to full extension of the shank produces a quicker, smoother gait with increased clearance between the prosthetic foot and the floor.

Two prototypes of a spring mechanism to initiate thigh flexion in a hip-disarticulation or hemipelvectomy prosthesis have been made. A set of drawings has been made to incorporate one method into a pylon construction for the thigh, and a prototype of this model is being made and assembled.

Using the polycentric knee for stability it has also been possible to align the prosthesis to provide for easier knee flexion thus reducing the spring force required for initiating thigh flexion.

University of California at Los Angeles
Biotechnology Laboratory
John Lyman, Ph. D.

Current research activity is part of a continuous goal to achieve optimal control loops for externally powered prostheses. The research is divided into the following sub-projects:

Development of an Arm Simulator

A low inertia simulator capable of three dimensional movement (flexion-extension, shoulder rotation, and shoulder elevation) has been designed and constructed, with its adjacent control circuit. Preliminary experiments in using the device in evaluating various control loop configurations revealed that further improvement will be required in its power amplifier. An instrumentation system has been set in order to use the arm simulator in studying operator ability to use the various control system configurations such as position, velocity, and bang-bang.

Application of Fluidics to Prostheses Control

Supplementary to the current investigation of suitable electronic circuits, a pneumatic control system utilizing fluidic devices was designed. The system comprises a newly developed force to pressure transducer, a fluidic sign detection and amplitude conversion circuit, and a simple actuator system attached to the shoulder joint of an AIPR arm, thus providing a concept for controlling movements of 1 deg. of freedom. This basic movement control unit in turn is intended to become a portion of a movement pattern generating system whose logic description also has been developed. The devised movement coordination system is to be operated through two transducers and provides for an automatic subsequence for the task of arm flexion; it allows for independent corrections of direction or distance respectively, and it inhibits opposing control signals automatically. Further development of this concept, in order to control and coordinate movements of more than 2 deg. of freedom, is intended after experimental studies on the performance of the system so far devised have been made. Simultaneously investigation of the feasibility for utilizing stepping (motor) devices to improve the positioning accuracy and the "hold" function of the actuator system is suggested.

Control Signal Sources

An evaluation study of the harness control transducers that were previously developed is underway. A comparative analysis between strain gage harness transducer and EMG signal sources is being made. The object is to determine, on the basis of information rate availability, which system is more suitable for prosthesis control.

Arm Movement Analysis

A detailed study of arm motions is in progress. This includes the analysis of certain motion patterns, the "control laws" which are involved, and a way to describe these by mathematical equations. The study will be executed on a hybrid computer. A literature survey was completed; experiment design and computer program have been completed.

University of California at San Francisco and Berkeley

Charles W. Radcliffe, Howard D. Eberhart, and James M. Morris

The polycentric/pneumatic unit has been completely redesigned along the lines outlined in the proposal for FY 1968. A single prototype unit has been constructed and is being prepared for fitting to an above-knee amputee on the UC–BL staff. The redesigned unit includes a more compact pneumatic cylinder with improved needle valve design, a high-strength welded sheet-metal main shank structure, all molded nylon bearings, high-rigidity lightweight linkage, and a system of socket coupling specifically designed for use with a rigid polyurethane foam socket extension.

Fifty units of the improved design for the UC–BL pneumatic swing-control unit have been installed in the new cast-aluminum shank with rigid polyurethane cosmetic shank cover; these units have been delivered to the Veterans Administration Prosthetics Center for further testing. The revised instruction manual is now in press.

A prototype has been constructed of the UC–BL pylon-type above-knee prosthesis with single-axis knee joint. The shank unit for the new model was formed on epoxy-aluminum dies and shows promise of a stronger and lighter unit at a much lower cost. Design and testing of accessory components, such as the metal knee, improved expansion couplings, ankle rotation devices, and built-in alignment devices, are planned.

A prototype polycentric linkage has been constructed for use with a prosthesis for a knee disarticulation. Design studies will be continued; a study of improved fitting techniques will be carried out concurrently.

A sample molded SACH foot, incorporating a cast-aluminum keel structure and a horizontal plane of attachment above the malleoli, has been prepared at UC–BL. This design incorporates the recommended SACH foot contours in the toe section, arch, and heel as well as a conical quick disconnect for use with a 1½-in.-diameter-aluminum pylon. In addition, a master wood pattern for a size 11 SACH foot incorporating the recommended shape factors has been prepared and forwarded to VAPC. It is anticipated that this master pattern will be used as a guide to proper SACH foot shape by manufacturers of molded SACH feet.

Biomechanical studies of the lower extremities and trunk are continuing. The ultimate aim is to provide a comprehensive picture, in three dimensions, of the biomechanical roles of all body segments in normal human locomotion.

VA Hospital, Seattle, Washington

Ernest M. Burgess, M.D., and Joseph H. Zettl

Clinical research of immediate postsurgical prosthetics management and application of this concept of amputee management and rehabilitation continued.

Efforts were directed to develop further and improve present surgical techniques, specifically in our investigation of the geriatric amputee with ischemia. Various preoperative assessment techniques of extremity blood flow are being studied to allow for more accurate amputation level selection.

Technical refinements consisted of clinical evaluations of new interface materials, such as Silastic foam pads. Polyurethane foam will be considered for the same purpose as soon as contouring difficulties can be overcome. The above-knee suspension system is under study for possible improvement of its effectiveness. Also preformed adjustable quadrilateral above-knee socket brims of plaster of paris are being evaluated further and clinically tested.

Follow-up data and pertinent information on all available patients are carefully gathered, recorded, and maintained.

Major educational activities were conducted in cooperation with the Veterans Administration. Two seminars on Immediate Postsurgical Prosthetics Management were held in Miami and in Houston.

SENSORY AIDS

Howard Freiberger, A.M.

Electronics Engineer, Research and Development Division
Prosthetic and Sensory Aids Service, Veterans Administration
New York, N.Y. 10001

Fabrication of Obstacle Detectors for the Blind

Bionic Instruments, Inc., Bala Cynwyd, Pennsylvania 19004

Thomas A. Benham, J. Malvern Benjamin, Jr., D. Ridgeley Bolgiano, and E. Donnel Meeks, Jr.

An article was submitted to the Bulletin entitled "A Review of the Veterans Administration Blind Guidance Device Project." This article, which appears elsewhere in this issue, covers the development of the C4 laser cane from its inception. Also included is a review of various other guidance devices for the blind that have been suggested and tried.

New developments have evolved around the construction of C4 canes. There was also some development work in one-piece and collapsible boron-stiffened canes.

Research on Audible Outputs of Reading Machines for the Blind

Haskins Laboratories, Inc., New York, N.Y. 10017
Franklin S. Cooper, Ph. D., and Jane Gaitenby

The objective of the work at Haskins Laboratories is to find practical methods for generating spoken English from literal text as the output of a reading machine for the blind. Three different types of spoken output are being investigated, each offering individual advantages (in voice quality, for example) and disadvantages (operating cost, additional development time, etc.).

The simplest of these methods generates *compiled speech* from a vocabulary of spoken words. The words were recorded originally on magnetic material striped on cards, one word per card. These word recordings, transferred to digital storage, can be reassembled, i.e., compiled, into the sequence required by the message at hand. The resulting speech is quite intelligible and realistic; reading speeds of 120 words per minute pose no problem. Recent work on this system has been the completion and testing of the PCM equipment for converting the word recordings into digital form for storage on magnetic tape, and for the reverse process of reading the magnetic tapes back into speech. A paragraph-length test passage constructed in this way was converted into speech at different rates (with minor distortions of pitch and formant frequencies) in order to find the optimum choice of playback speed, which seems to be about 10–15 percent faster than the original recording rate. The programing necessary for automating the system and generating page-length readings is underway.

A second type of audible output is *re-formed speech.* This also uses information stored on a word-by-word basis, but the items stored are the control parameters for a formant-type speech synthesizer. Advantages are better, faster, and more natural speech and a much reduced storage requirement—which allows lower operating costs as well as a larger vocabulary without need to spell missing words. A penalty is that, for each word in the vocabulary, the control parameters must be obtained by measuring spectrograms of the spoken word and storing them in the computer—a lengthy task. Current work on re-formed speech is aimed at mechanizing these measurements. The sound spectrogram of a word will be optically superimposed on the screen of our computer display tube and the formants can then be tracked (with the cathode-ray spot) by a hand-held "mouse" that controls the computer while entering measurements directly into its memory. The display equipment is on hand, the mouse is essentially complete, and the programs for tracking and entering data are being written.

The third method of generating speech is *synthesis-by-rule.* This has moved much nearer realization than seemed likely as little as a year ago. Synthesis-by-rule has many inherent advantages, but it also involves much more research to achieve speech naturalness. Three stages are involved in going from the letter identities of the printed text to spoken output: one is to convert the graphemes into phonemes, then phonemes to control parameters, and finally control parameters into synthetic speech with a formant-type synthesizer. During the past year, Dr. Mattingly has completed his rules for sentence synthesis and his tables of parameters for general American phonemes. These have been used with a computer-driven synthesizer to produce an output of highly intelligible, if not totally natural, synthetic speech for numerous randomly chosen texts. Further improvements are certainly anticipated, but already the second and third stages of synthesis-by-rule are sufficiently operational to deserve serious testing. Progress has been made also on the first stage of the process, the grapheme-to-phoneme conversion. A pilot program was prepared by Miss Gaitenby for converting the letter sequences of words into phoneme sequences including syllabification and word stress prescription by rule. Tests of various texts, not extensive, but probably representative of popular periodicals, indicate that at least 85 percent of the words of normal sentences are acceptably converted to sound by these rules, used in concert with Dr. Mattingly's synthesis program. The rules, thus far, have been simulated rather than programed for automatic computation. They are, nevertheless, fully explicit and so can be converted into a computer program in due course. The present rules deal primarily with lexical stress and make their phonemic and word stress assignments either on the basis of number of syllables in a word or on the basis of affixes. (A mere handful of suffixes—and a few prefixes—play a dominant role in English vocabulary, and often serve to predict stress in the words in which they occur.)

In summary, work is progressing on all three types of speech output for a reading machine, with pilot tests imminent for compiled speech and reasonably near for speech synthesized by rule, provided unexpected difficulties do not arise in converting the grapheme-to-phoneme prescriptions into an operating computer program. [The work on reading machines is closely related to other research on speech perception and production underway at Haskins Laboratories. A summary account of this work, and other research in the Laboratories, was published during the period under review.]

The Development and Evaluation of a Personal Reading Machine for the Blind

Mauch Laboratories, Inc., Dayton, Ohio 45439
Hans A. Mauch and Glendon C. Smith

The production version of Mauch Laboratories' Recognition Machine has been given the name "Cognodictor" to distinguish it from the earlier bench model (Recognition Prototype II). The Cognodictor design is progressing smoothly and two major sections, the Word Synthesizer electronics and a new design Word Storage Unit, have been built and tested.

The Word Synthesizer electronic circuit uses seven transistors and nine integrated circuits on a single printed circuit board (4½ x 4½ in.) to select and amplify one out of 31 spelled-speech letters recorded on optical sound tracks of the rotating drum-type audio memory. The commercial circuit this section replaced used 47 transistors and 160 diodes located on seven circuit boards.

The new Word Storage Unit uses 25 complex function integrated circuits on one 4½ x 4½ in. board to provide storage for up to eight binary signals representing the letters being recognized by the machine. Additional storage capacity can be provided by using a second card, if required. The new Word Storage Unit also replaces up to seven printed circuit boards with one board the same size. These two sections designed for the Cognodictor will contribute to meeting the cost and size objectives for the production version of the recognition machine. The remainder of the circuitry will be redesigned to use integrated circuits, and three Cognodictor prototypes will be assembled for use by blind subjects.

The Visotactor B and Visotoner direct translation reading aids in the field were improved by adding a speed dependent viscous damping device to the axle of the proximal roller. This miniaturized device takes the place of the line change knob and enables the user to "pace" his scanning speed by maintaining a steady pulling force.

A thumbwheel control for the tactile stimulator driving voltage was designed and added to one Visotactor B prototype. This control can be adjusted by the user to vary the intensity of the fingertip stimulators over a wide range. Users of the Visotactor have said that such a control would help compensate for fatigue and difficult reading material.

The experience of blind users of the six Visotoners and four Visotactor B's has resulted in several design changes in addition to the two discussed above. The lamp assembly was redesigned to replace the clip-in mounting by a more secure attachment using machine screws. The lamp life is expected to be 10,000 hours or more so that user replacement is less necessary. Improvements in the printed circuit design of both aids were made to reduce the incidence of faulty connections. The Visotoner circuit specifications were changed to facilitate recording its output.

Determination of Performance Attainable with the Battelle Optophone

American Center for Research in Blindness and Rehabilitation, Newton, Massachusetts 02158

Leo H. Riley, M.D., and Mrs. Ruth Morris

A three-speed, motor-driven, mechanical tracker was developed by Mr. Edward Luttropp and finished by November 1967. Meanwhile, both of the Center's optophones developed electronic problems which were finally corrected.

Miss B. F. resumed training on November 29, 1967. She remembered what she had learned 2 years previously and required no teaching. She read 8.0 words per minute on her first test. (She originally scored 2.0 words per minute on the same test three years ago.) She found the mechanically driven board a great advantage. She appreciated the "pacing" which it provided, pointing out that she could concentrate better when she did not have to use her hands so much and that the mechanical device produced a much more "constant, smooth speed."

Miss B. F. died February 13, 1968, after a brief illness. Her optophone was assigned to Miss C. C. on February 27, 1968. By the end of March, she had finished Lesson 3. The demands of her school work made it difficult for her to find sufficient time to practice on the optophone. She is being assisted by her mother in her home.

Miss F. B. started with the other optophone on January 14, 1968. She has finished Lesson 12, having done two lessons a week by herself with constant teaching from Mrs. Morris through Lesson 8. After Lesson 8, she spent more time studying the tapes by herself and now reads more easily. On Test 1, she read 5.9 words per minute on March 27, 1968. Her problems have been principally mechanical. Mrs. Morris and Mr. Luttropp have solved these as they occurred, but progress in learning is still hampered by frequent inconsistencies in the taped lessons, especially in the spacing of words or lessons on the tapes, and also by less frequent distortions of the taped tonal quality.

We plan to have the Misses F. B. and C. C. continue this same program, using Mr. Luttropp's mechanical tracker under the guidance of Mrs. Morris. Both these subjects seem sufficiently motivated to do well with the optophones. We are satisfied so far that allowing the subject to use the optophones at home is a better approach than having the subjects come to the Research Center to use the optophones as was originally planned.

Evaluation of Ultrasonic Aid for the Blind

American Center for Research in Blindness and Rehabilitation, Newton, Massachusetts 02158

Leo H. Riley, M.D., and Mrs. Ruth Morris

The results of the recently completed field tests are being summarized for possible publication.

The Center is awaiting receipt of some instructional text and tape-recorded materials, which are being used at Hines and at Palo Alto. It is planned to make use of these materials with selected subjects.

Reading and Mobility Aids for the Blind, Centrally Directed Clinical Application Program

Central Rehabilitation Section for Visually Impaired and Blinded Veterans, VA Hospital, Hines, Illinois 60141

John D. Malamazian and Harvey L. Lauer

Working with the Mauch Visotoners (optophones) and the Mauch Visotactors B (tactile optophones), it is endeavored to bring this equipment from the laboratory into use in the following four ways:

Testing

The Mauch viscous damping pacing aid was added to several reading machines and found to be valuable for reading, both with and without the Colineator (tracking board), and for making recordings of the Visotoner output. It reduces pace variations and results in higher legibility.

Earphones were tested and equipment calibrated for use with fitted earmolds. The results will be a more uniform ear coupling for students. An accessory for making tape recordings of improved quality was tested and also an accessory was used which facilitates note-taking while reading.

Developing Instructional Aids and Teaching Skills

A series of instructional Visotoner tape recordings was made and is now being evaluated. These include letter, word, and sentence studies. Several days were used in working with Miss Margaret Butow of the Hadley School for the Blind. This work included testing equipment, help in beginning work with a deaf-blind student, and assistance in developing the Hadley School home study course for screening Visotoner candidates.

A teaching manual was drafted for users and instructors of the Visotactor B. An instructor's monitor for the Visotactor was devised by Mr. Lauer which is proving very helpful in demonstrating and in working with beginners. Tactile aids were developed and duplicated, which illustrate letter shapes and the stimulus patterns of the Visotactor.

Direct Teaching of Students

The Visotoner—Seven students were given instruction during the period just prior to this writing, four of whom were selected for continued training. Of these, two have reached Lesson 150 (three-fourths of the Battelle Course). These two students are reading typewritten material in addition to the course material. (The reading speeds of all students vary between two and ten words per minute.) New personal uses for the Visotoner continue to be found.

The Visotactor B—A veteran who began working with this instrument in November has reached Lesson 70. Mr. Lauer is currently developing his own skill with the Visotactor.

Public Information

An article, "The Visotoner: A Personal Reading Machine for the Blind," by Harvey Lauer which appears elsewhere in this issue of the Bulletin is also slated for publication in three other periodicals: The New Outlook for the Blind, The New Beacon, and The Home Teacher. Tape recorded demonstrations have been published in small "taped" periodicals with small circulations. Correspondence is carried on with agency personnel and equipment is demonstrated for interested persons. A presentation was made by Mr. Lauer at the Midwest Conference of Home Teachers in Columbus, Ohio, in September 1967, and the occasion was used to make a helpful and interesting trip to Mauch Laboratories in Dayton, Ohio.

Development of Correspondence Courses for Personal Reading Aids for the Blind

The Hadley School for the Blind, Winnetka, Illinois 60093

Donald W. Hathaway and Margaret Butow

A master recording is soon to be made of the 25-lesson taped correspondence course designed to screen economically candidates for more extensive personalized training in optophone-style reading machines such as the VA-Mauch Visotoner. Current activities center around perfecting the specialized techniques necessary for recording and duplicating the training tapes.

New letters of the alphabet will be introduced at the rate of between two and five letters per lesson. Eight to ten words will also be introduced in each lesson, and there will also be one to three sentences. Tests employing words produced in the "code" of the machine will be included in each lesson. Part of each test will allow for immediate check and reinforcement as some answers will be provided in the tape. Other test selections and oral questions will have to be answered and forwarded to the course instructor at Hadley School for the Blind for grading and comment. In the more advanced lessons of this preliminary screening course there will be examples of materials from the Battelle Memorial Institute 200-hour training course and demonstrations of the effects of alignment of the probe to the line-of-type and of the size-of-type adjustment. The effects of illuminating-lamp brightness setting will also be touched on. In the 25th and final lesson of the course there will be a five-part final examination.

Development of Test Procedures for Evaluation of Binaural Hearing Aids

Northwestern University, Evanston, Illinois 60201

Raymond Carhart, Ph. D., and Wayne O. Olsen, Ph. D.

A part of the current work on this project involves the development of test materials in which monosyllabic words are presented against modulated white noise competition. The use of modulated white noise is currently being studied since other work in the laboratory has indicated that white noise, modulated by a 10 dB step every 125 msec., produces masking very much like the interference provided by the second talker of the competing message test. Tests of speech discrimination employing noise competition are more easily replicated than competing message tests.

Work is also underway with a system in which the output of a hearing-aid microphone in a conventional behind-the-ear hearing-aid shell is led to different hearing-aid receivers through an adjustable clipping unit. The use of different hearing-aid receivers primarily affects the bandwidth of the system, while adjustments on the clipping unit determine the amount of harmonic and intermodulation distortion. This system allows systematic study of the influence of bandwidth and distortion on speech intelligibility achieved by hearing-impaired persons for speech amplified and distorted by this system.

Two matched systems such as described above have been built in order to study further monaural and binaural hearing-aid use. In this work on monaural and binaural hearing relatively low-level low-frequency noise such as present in most environments is utilized in addition to the other competing signals described above, in order to create conditions which more closely reflect everyday listening situations.

Electroacoustic Characteristics of Hearing Aids

Houston Speech and Hearing Center, Houston, Texas 77025

James Jerger, Ph. D.

A full report on the selected 21 commercially available hearing aids which were on the VA contract list for Fiscal Year 1966 will be published in the next issue of the Bulletin. It will appear under the title "Effects of Electroacoustic Characteristics of Hearing Aids on Speech Understanding." The article will be broadly concerned with the relationship between the electroacoustic characteristics of hearing aids and their successful use by the hearing impaired.

The Effects of Distortion on Hearing-Aid Performance

Auditory Research Laboratory, VA Hospital, Washington, D.C. 20422

George Simon, Ph. D.

In the Auditory Research Laboratory, VAH, Washington, work continues on analyses of earmold design, receiver substitution, and CROS hearing-aid performance. This coming year, even though Dr. George Simon will be leaving for Memphis State University, Memphis, Tennessee, an intensive study will be made of the performance of in-the-ear hearing aids. In addition to the articles appearing in this issue, there is at least one paper on hearing-aid investigation to be presented at the November 1968 ASHA Convention in Denver, Colorado.

Results of the work in progress in this laboratory indicate promise for the contribution of new analysis equipment in the measurement of hearing-aid performance. Further, development of a semantic differential of quality will materially assist investigators in relating subjective performance with hearing aids to electroacoustic characteristics.

Influence of Input and Gain Values upon Electroacoustic Properties of Hearing Aids

BioCommunications Laboratory, University of Maryland, College Park, Maryland 20742

G. Donald Causey, Ph. D.

The first year of contractual arrangements with the University of Maryland has resulted in the completion of a new BioCommunications Laboratory engaged solely in psychoacoustic research to further understanding of hearing-aid characteristics, evaluation, and use. A thorough survey of all past investigations in the area of speech intelligibility materials has been conducted. This knowledge is being utilized in efforts to develop a new set of materials which, it is hoped, will replace present materials in use by the VA to help in setting compensation levels and for hearing-aid evaluation purposes. Once available, these materials and others will be utilized to correlate speech intelligibility with physical measures of hearing-aid performance.

NOTES AND NEWS

PORTLAND INTRA-VA COURSE IN PROSTHETICS

The Prosthetic and Sensory Aids Service of the Department of Medicine and Surgery, Veterans Administration, conducted the third in a series of Intra-VA training courses in prosthetics from April 29 through May 3, 1968, at Portland, Oregon. Emphasis was placed on immediate postsurgical prosthetics.

The course which was attended by 35 VA physicians, therapists, prosthetic representatives, and orthopedic shop technicians included laboratory sessions held at the VA Hospital in Portland.

The course was also attended by 11 prosthetists and therapists from non-VA organizations.

ZWORYKIN RECEIVES NATIONAL ACADEMY OF ENGINEERING AWARD

Vladimir K. Zworykin, awarded The National Academy of Engineering Third Founders Medal, is noted for his invention of the first practical picture transmission tube. Among his many other electronic inventions in the fields of engineering and medicine, Dr. Zworykin is remembered by many as a pioneer in the development of reading aids for the blind. He developed a device consisting of a hand-held probe or stylus based in part on the optophone invented by Dr. E. E. Fournier d'Albe in 1914. Dr. Zworykin's reading device produced audible sounds whose tone patterns depended on the shapes of the letters as the probe or stylus scanned them. Our present day small optophones, Visotoners and Visotactors, are direct descendants of the Fournier d'Albe and Zworykin devices.

BIOMEDICAL ENGINEERING SEMINAR AT U. OF MIAMI

A seminar was held at the University of Miami on Biomedical Engineering on March 28, 1968. The seminar was attended by many orthopedic surgeons as well as biomedical engineers.

Dr. Murphy of the Prosthetic and Sensory Aids Service of the Veterans Administration lectured at the seminar on "Future Possibilities for Electro-Mechanical Limb Prostheses."

CPRD FIFTH WORKSHOP PANEL ON LOWER-EXTREMITY ORTHOTICS

The meeting of the Fifth Workshop Panel on Lower-Extremity Orthotics was held in Atlanta, Georgia, April 3–4, 1968. Anthony Staros, Director of the Veterans Administration Prosthetics Center was chairman, and A. B. Wilson, Jr., of the Committee on Prosthetics Research and Development and H. Thranhardt of J. E. Hanger, Inc. were co-chairmen of Group A & B discussions, respectively.

The meeting was opened with an introduction by Mr. Staros and followed with a report of the "Workshop on the Human Foot and Ankle, Design and Development Implications." Group A, chaired by Mr. Wilson, discussed "Orthopedic Disability Analysis and Development of Criteria for Lower Extremity Brace System Design"; group B, chaired by Mr. Thranhardt, covered "Brace Structures, Materials and Special Devices."

Before adjourning the meeting, a session was spent on new items with presentations by Mr. Rosenquist of the Pope Brace Company, Professor Radcliffe of the University of California at Berkeley, Mr. McIlmurray of the VA Prosthetics Center and many others.

The following lists those who took part in Group A and B discussions:

GROUP A

F. A. Clippinger, Durham, N.C.
H. Elftman, New York, N.Y.
C. Fryer, Chicago, Ill.
H. A. Mauch, Dayton, Ohio
C. A. McLaurin, Toronto, Ont. Can.
E. F. Murphy, New York, N.Y.
E. Peizer, New York, N.Y.
C. Radcliffe, San Francisco, Calif.
W. Roth, Burlington, Vt.
A. Sarmiento, Miami, Fla.
A. W. Serkiz, Columbus, Ohio
C. Scott, Los Angeles, Calif.
R. Snelson, Los Angeles, Calif.
J. E. Traub, Washington, D.C.
R. Wirta, Philadelphia, Pa.

GROUP B

J. Campbell, San Francisco, Calif.
T. Engen, Houston, Texas
R. Lehneis, New York, N.Y.
F. Harmon, Atlanta, Ga.
B. Ewing, Atlanta, Ga.
C. Fillauer, Chattanooga, Tenn.
W. McIlmurray, New York, N.Y.
C. Rosenquist, Columbus, Ohio
B. Titus, Durham, N.C.

WALKING WITH A CAST

Getting the patient out of bed and walking as soon as possible after surgery is a popular trend with many surgeons today. With the introduction of immediate postsurgical prosthetics fitting another step was accomplished in this concept, and surgeons are beginning to look for other possible applications.

One recent development tried by Orthopedic Surgeon Ernst Dehne of the Veterans Administration Hospital in Memphis is "walking on a broken leg." Dr. Dehne concluded that a patient should not have to stay in a cast and flat on his back for weeks—instead, "let him start walking as soon as the cast is dry." A broad-scale test was carried out at the Army's Fitzsimons General Hospital in Denver where 56 servicemen with open-tibial fractures were treated this way. Within 24 hours after setting the cast, Fitzsimons doctors had their patients on crutches encouraging them to put as much weight on their broken legs as they could tolerate.

The results proved promising. The average time in plaster was 19 weeks, but some got out in as little as seven weeks. Atrophy was kept to a minimum, all fractures healed, and there were no amputations.

"PROJECT SLIDES" COMPLETED

The Prosthetic and Sensory Aids Service of the Veterans Administration has completed preparation of their second series of "Project Slides" dealing with prosthetic and orthotic devices and components. The sets, consisting of 100 updated slides and captions, include a section on immediate post-surgical prosthetics management.

The Veterans Administration has distributed the sets to 80 VA hospitals requesting that the slides be made available on a loan basis to responsible locally interested individuals and organizations.

Sets of slides and captions will also be distributed to every physical and occupational therapy school in the United States by the Committee on Prosthetic-Orthotic Education of the National Academy of Sciences-National Research Council. In addition, sets are being sent to all prosthetics clinics with residency training programs.

The International Society for the Rehabilitation of the Disabled will also make sets available to selected people and organizations outside of the United States.

DR. MURPHY HONORED

Dr. Eugene F. Murphy, Chief, Research and Development Division, Prosthetic and Sensory Aids, was recently elected to the National Academy of Engineering. Election to the Academy is the highest professional distinction that can be conferred on an American engineer and is limited to those who have made "important contributions to engineering theory and practice" or who have demonstrated "unusual accomplishments in the pioneering of new and developing fields of technology."

Fifty engineers were elected this year, making a total membership of 237. Membership in the Academy entails participation in its principal activity: rendering advice to the Federal Government in important policy matters related to engineering.

We are proud of our Dr. Murphy for having achieved this honor.

STUDY OF 851 BLINDED VETERANS PUBLISHED BY AMERICAN FOUNDATION FOR THE BLIND

The 338-page study recently published by the American Foundation for the Blind entitled "851 Blinded Veterans: A Success Story" was supported by the Foundation, the Veterans Administration, and the Blinded Veterans Association. It was carried out under the direction of the Foundation's research department, with Dr. Milton D. Graham serving as project director and Robert L. Robinson as research director.

The 851 are male veterans of World War I, World War II, and the Korean conflict. All have at least 70 percent visual loss. Through interviews and examinations which were conducted in 1964 in ten VA medical outpatient clinics in large metropolitan areas across the country, information was obtained about demographic, social, ophthalmological, audiological, psychological, and general health characteristics.

According to the study of 851 blinded veterans of the three wars, blind persons can achieve a place in the community generally comparable to that of their sighted peers if they receive adequate medical, social, and rehabilitation services.

Some of the general findings reported in the study are as follows:

Comparison of the study and United States census data reveals that the blinded veterans are in many ways similar to the general male population and/or the male veteran population: mean age is forty-six; they are generally heads of their households; most own their own homes and live with their wives in an average-sized family; the proportion of nonwhites to whites is similar.

VA social workers who interviewed the blinded veterans found them mostly positive in their handling of rehabilitation experience, family situations and relations with the community, and in their general pattern of family activities.

Ninety percent of the blinded veterans have been employed at one time or another since they left the military service, but only 38 percent were employed at the time of the study, with an additional 5 percent looking for work. In part, age accounts for the low percentage of employment (many are already of retirement age).

The average household income in the United States in 1964 was $6,600; for the blinded veterans' household, it was $8,600. Financial flooring, in the form of disability compensation, is one of the factors contributing to this difference in reported family household income.

The blinded veterans with residual vision showed a surprising lack of concern about eye care: half of the sample had not seen a doctor about their eyes in 5 years, and only about 25 percent had seen a doctor during the year immediately before the study.

During the analysis and writing phase of the project, the Veterans Administration was informed of the findings. The major information reported to the VA was that there was seriously inadequate eye care among the sample group and that many had multiple impairment and chronic health conditions.

Partially as a result of the findings, the Veterans Administration was prompted to make some significant changes in its program for blinded veterans. Among the changes were:

The VA appointed a consultant on blindness to work out of the office of the chief of Blind Rehabilitation Services in the VA Central Office. It is hoped that such a consultant will be located at each of the Veterans Administration Rehabilitation Centers.

Because the Blind Rehabilitation Center at Hines Veterans Hospital (Hines, Illinois) has a long waiting list, a second center was opened in 1967 at Palo Alto, California; a third is planned for West Haven, Connecticut.

The Veterans Administration has decided to make a concerted effort to seek out blinded veterans who need assistance of any type. (This contrasts with the former VA practice of taking a passive role in the provision of services.)

The report concludes by stating that "the story of the sample is largely a success story. Visually impaired and often multiply impaired by chance in the service of their country, they were offered in compensation many opportunities (personal rehabilitation, vocational and academic training, medical services, and so on), and they took advantage and used them well.

"Their record is a tribute to all concerned. It should be well studied by anyone who believes that man can triumph over impairment and handicap."

The book costs $4.25 and may be obtained from the American Foundation for the Blind, 15 West 16th Street, New York, New York 10011.

RECENT PATENTS[a]

Flexion Back Brace: Fred L. Stuttle, assignor to Florida Brace Corporation, Winter Park, Florida. A flexion back brace for treating the lumbosacral area to change a lordotic back to an active flat back. The brace is made up of interchangeable prefabricated parts adapted to be easily and quickly assembled as a complete unit. (Patent No. 3,351,053, Nov. 7, 1967; filed Nov. 13, 1962, Serial No. 236,924; 7 claims.)

Mechanical Hand Having Computer-Type Drive Mechanisms for Producing Numerous Hand Articulations Similar to a Human Hand: Joseph A. Gentiluomo. An anthropomorphic mechanical hand which can be articulated to provide finger and thumb motions separate and distinct from one another or in various combinations with one another. According to the inventor, the hand has a novel and relatively simple finger and thumb construction making them easily operable and capable of grasping diverse objects with substantial strength if needed. (Patent No. 3,345, 647, Oct. 10, 1967; filed Oct. 7, 1963, Serial No. 314,148; 6 claims.)

Method of Muscular Stimulation in Human Beings to Aid in Walking: Franklin F. Offner. A method for stimulating in a periodic manner the denervated tibialis anticus and peroneus longus muscles of the leg, in order to obtain near normal use of these muscles in walking. In this method, the pulse-type stimulating current to these muscles is controlled by the periodic up and down movement of the heel. Raising of the heel turns on, and lowering of the heel turns off, the stimulating current. (Patent No. 3,344,792, Oct. 3, 1967; filed Jan. 13, 1965, Serial No. 426,476; 1 claim.)

Self-Operable Detachable Power Unit Attachment for Wheelchairs and Power Control Unit Therefor: Shawn M. Solomon. A device to power operate a wheelchair that can be attached to any standard wheelchair without modification of the wheelchair's existing structure. According to the inventor, the unit can be readily removed from and attached to the wheelchair by the user, without assistance, while he is occupying the chair. (Patent No. 3,351,148, Nov. 7, 1967; filed Oct. 24, 1965, Serial No. 504,316; 24 claims.)

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[a] Patents may be ordered by number from the Commissioner of Patents, Washington, D.C. 20231, at 50 cents each.

PUBLICATIONS OF INTEREST

PROSTHETICS

An Above-Knee Temporary Pylon for a Below-Knee Amputee, Kenneth L. Bowmaker and James L. Werner; Phy. Therapy, 48(1): 31–33, Jan. 1968.

A Design Study of a Hydraulically Operated Artificial Arm Powered by Normal Walking, R. D. McLeish; Med. & Biol. Engng., 6(1): 3–17, Jan. 1968.

An EMG-Operated Control System for a Prosthesis, J. During and T. C. M. Van Miltenburg; Med. & Biol. Engng., 5(6): 597–601, Nov. 1967.

An Evaluation of the Patellar Tendon-Bearing Prosthesis, B. E. McConville, Elmer H. Kennedy, and Marten Schouten; International Surg., 47(4): 377–381, April 1967.

External Power and the Amputee: An Engineer's View, Andrew L. Lippay; Inter-Clinic Infor. Bull., VII(5): 7–12, Feb. 1968.

Hydraulics for Prosthetic Devices, David W. Lewis; Ortho. & Pros., 22(1): 23–28, Mar. 1968.

Immediate Postsurgical Prosthetic Fitting of Childen and Adolescents Following Lower-Extremity Amputations, Ernest M. Burgess and Robert L. Romano; Inter-Clinic Infor. Bull., VII(3): 1–10, Dec. 1967.

A Modified Modification (Cosmetic Improvement of a Good Product), Siegfried W. Paul; Ortho. & Pros., 22(1): 47–48, Mar. 1968.

The Myo-Electric Prosthesis, H. M. Hague; Rehab. in Canada (17): 14–17, Fall-Winter, 1967–68.

New Hope for the Patient With Severe Upper-Extremity Deficiencies; Externally Powered Prostheses, Maurice Mongeau; Inter-Clinic Infor. Bull., VII(5): 1–6, Feb. 1968.

The Otto Bock All Plastic Above Knee Prosthesis for the Geriatric Amputee, Fritz K. Schoreder and John R. Hendrickson; Ortho. & Pros., 22(1): 29–32, Mar. 1968.

Prostheses Powered by Carbon Dioxide, Camille Corriveau; Inter-Clinic Infor. Bull., VII(5): 13–16, Feb. 1968.

Prosthetic Spinal Support Following Hemipelvectomy in a Paraplegic Patient, Sidney M. Dinsdale, Malcolm Peterson, and Theodore M. Cole; Arch. Phys. Med. & Rehab., 49(1): 42–44, Jan. 1968.

The Rotterdam Prosthesis—A Simple Prosthesis for the Aged, S. Braadbaart; J. Am. Geriatrics Soc., 15(6): 560–563, June 1967.

Temporary Prosthesis with Adjustable Socket, William S. Brownsey and Carlton Fillauer; Phys. Therapy, 47(12): 1129–1131, Dec. 1967.

Twenty Months Experience with the "PTS," Sam E. Hamontree, Howard J. Tyo, and Snowdon Smith; Ortho. & Pros., 22(1): 33–39, Mar. 1968.

The Use of Lower Extremity Prosthetic Limbs by Elderly Patients, Albert D. Anderson, Victor Cummings, Samuel L. Levine, and Arthur Kraus; Arch. Phys. Med. & Rehab., 48(10): 533–538, Oct. 1967.

A Work Prosthesis for the Partial Hand Amputee, B. E. McConville and P. J. Brittain; Clinical Orthopaedics, (50): 231–234, Jan.-Feb. 1967.

ORTHOTICS

Brace to Aid Weak Triceps Surae Muscle, Carl V. Granger and Paul Schumacher; Arch. Phys. Med. & Rehab., 49(2):105–107, Feb. 1968.

Dynamic Strain Analysis of Below-Knee Orthopedic Braces, A. Magora, G. C. Robin, E. Adler, A. Libai, and E. Eitan; Amer. J. Phys. Med., 47(1):31–40, Feb. 1968.

Experimental Plastic Short Leg Brace, Robert H. Jebsen, Bernard C. Simons, and Paul J. Corcoran; Arch. Phys. Med. & Rehab., 49(2):108–109, Feb. 1968.

SENSORY AIDS

An Intensive Speech and Language Program In the Rehabilitation Process of Multihandicapped Children, Dorothy Doob; Rehab. Literature, XXIX(1):8–10, Jan. 1968.

Research on Reading Aids for the Blind—A Dilemma, Patrick W. Nye; Med. & Biol. Engng., 6(1):43–51, Jan. 1968.

SURGERY

B–K Amputations Versus A–K in Gangrene, Mortality Lower in Below-Knee Group; Braces Today, Newsletter of the Pope Foundation, Inc., p. 1, Feb. 1968.

Some Highlights in the History of Amputation Reflecting Lessons in Wound Healing, Owen H. Wangensteen, Jacqueline Smith, and Sarah D. Wangensteen; Bull. Hist. of Med., XLI(2):97–131, Mar.-April 1967.

GENERAL

Above-Knee Amputee—Self-Help Stump Wrapping, Vincent J. Bruno; Am. Corr. Therapy J., 21(5):156–158, Sept.-Oct. 1967.

Effects of Distracting Movements on the Control of Trained Motor Units, John V. Basmajian and Therese G. Simard; Amer. J. Phys. Med., 46(6): 1427–1449, Dec. 1967.

Guide for the Identification, Evaluation and Regulation of Persons with Medical Handicaps to Driving, Julian A. Waller; The American Association of Motor Vehicle Administrators, 404 Madison Building, Washington, D.C. 20005, 1967.

Method of Kinematic Study of Normal Upper Extremity Movements, Thorkild J. Engen and William A. Spencer; Arch. Phys. Med. & Rehab., 49(1):9–12, Jan. 1968.

Method of Lifting Wheelchair Into Two-Door Sedan by Paraplegic Patient, Melvin J. Goldberg and Linda J. Davis; Arch. Phys. Med. & Rehab., 48(11): 615, Nov. 1967.

Modified Lofstrand Crutch, Donald O. Tootle; Phys. Therapy, 48(1):36–37, Jan. 1968.

A Multiphasic Study of Lower-Extremity Amputees, Kate H. Kohn, Lawrence Perlman, Marcel Neumann, and Edward Ho; J. Am. Med. Assn., 199:537–542, Feb. 20, 1967.

1018 Children with Skeletal Limb Deficiencies, Hector W. Kay and Sidney Fishman; Prosthetic and Orthotic Studies, New York University, Post-Graduate Medical School, Mar. 1967.

The Orthopedic Surgeon and the Occupational Therapist, Vernon L. Nickel; Occupational Therapy, XXII(2):86–88, Mar.-April 1968.

Physical Therapy in the Nonoperative Treatment of Scoliosis, Walter P. Blount and Jane Bolinske; Phys. Therapy, 47(10):919–925, Oct. 1967.

Role of Corrective Therapy in the Rehabilitation of Immediate Post-Operative Fitting of Lower Extremity Amputee, Florian Surdyk, Elmer Maurer, Paul Kostyniuk, and Hugh Doran; Am. Corr. Therapy J., 2(1):32–35, Jan.-Feb. 1968.

The Stand-Alone for Hip Flexion Contractures, Sharon Hebb; Phys. Therapy, 48(3):231–232, Mar. 1968.

Telemetering Electromyography of Muscles Used in Walking Up and Down Stairs, J. Joseph and Richard Watson; J. Bone & Joint Surg., 49–B(4):774–780, Nov. 1967.

CALENDAR OF EVENTS

Fourteenth International Congress of Logopedics and Phoniatrics, Paris, France, Aug. 1968. (For information: Dr. B. Vallancien, 16, rue Spontini, Paris XVIé, France.)

Twenty-Second World Medical Assembly, World Medical Association, Sydney, Australia, Aug. 5–10, 1968. (For information: World Medical Association, 10 Columbus Circle, New York, N.Y. 10019, U.S.A.)

Conference and Assembly of the Interprovincial Association of Prosthetists and Orthotists of Canada, Hotel Bonaventure, Montreal, Quebec, Canada, Aug. 22–24, 1968. (For information: Simon Slawner, C.P.O., Conference Chairman, 5713 Cotes des Neiges Road, Montreal 26, Quebec, Canada.)

Fifth International Congress of Physical Medicine, International Federation of Physical Medicine, Montreal, Canada, Aug. 25–31, 1968. (For information: Dr. Bernard Talbot, Secretary General, The Congress, 6300 Darlington Avenue, Montreal 26, Canada [735–3741].)

Fourth Pan-Pacific Rehabilitation Conference, International Society for Rehabilitation of the Disabled and the Hong Kong Joint Council for the Physically and Mentally Disabled, Hong Kong, Sept. 2–8, 1968. (For information: The Secretary, Fourth Pan-Pacific Rehabilitation Conference, P.O. Box 8696, Mongkok, Kowloon, Hong Kong or Secretary General, International Society for Rehabilitation of the Disabled, 219 East 44th Street, New York, N.Y. 10017, U.S.A.)

International Seminar on Technical Aids and Environmental Adaptations for the Disabled, International Committee on Technical Aids, Housing and Transportation of the International Society and the Comité National Français de Liaison pour la Réadaptation des Handicapés, Paris, France, Sept. 22–28, 1968. (For information: Comité National Français de Liaison pour la Réadaptation des Handicapés, 21 Rue Viète, Paris 17e, France or Secretary General, International Society for Rehabilitation of the Disabled, 219 East 44th Street, New York, N.Y. 10017, U.S.A.)

AOPA National Assembly, Hotel Radisson, Minneapolis, Minnesota, Sept. 27–30, 1968.

National Rehabilitation Association Annual Meeting, Roosevelt Hotel, New Orleans, Louisiana, Oct. 21–23, 1968.

Forty-Seventh Annual Convention of the National Easter Seal Society for Crippled Children and Adults, Sheraton-Boston Hotel, Boston, Massachusetts, Nov. 13–16, 1968. (Leon Chatelain, Jr., Washington, D.C., president of the National Society will preside; Thomas Teas, Mason City, Iowa, is convention chairman.)

The Third International Conference on Congenital Malformations, sponsored by the National Foundation (March of Dimes), The Hague, Netherlands, Sept. 8–12, 1969. (For information: Secretariat, Holland Organizing Centre, 16 Lange Voorhout, The Hague, Netherlands.)

Eleventh World Congress, International Society for Rehabilitation of the Disabled, Dublin, Ireland, Sept. 14–19, 1969. (For information: Mr. Joseph N. Malone, National Organisation for Rehabilitation, 25 Clyde Road, Dublin 4, Ireland or Secretary General, International Society for Rehabilitation of the Disabled, 219 East 44th Street, New York, N.Y. 10017, U.S.A.)

Eleventh International Congress of Orthopedic Surgery and Traumatology, International Society of Orthopedic Surgery and Traumatology, Mexico City, Mexico, Oct. 6–10, 1969. (For information: Dr. Juan Farill, Morena 854-Narvarte, Mexico 12, D.F.)

U.S. GOVERNMENT PRINTING OFFICE: 1968 O—309–346

NOTICE TO CONTRIBUTORS

We welcome contributions to the Bulletin. To facilitate publishing, please:

1. Type, in double space, the text, figure legends, footnotes, references, and tables on one side of letter-size, plain bond paper.

2. Leave margins of 1½ inches on the left and 1¼ inches on the right.

3. Capitalize title of paper and center. Below title, center author names(s) with degree or certificates. Then center position title, organization, and location (city and state).

4. Number pages consecutively. Each page *must* start with a new paragraph. Type preceding page short if necessary. Indent paragraphs.

5. All references must be cited by number in the text and listed numerically at end of paper.

6. Each figure must have a legend and be cited by number within the text. Type legends on separate sheet. Pencil in lightly on back of each glossy the figure number, author's name, and article title.

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8. For illustrative materials, submit 8 x 10 glossies with good contrast. Line drawings should be in India ink. Do not dent glossies or art work with paper clips. All figures must be suitably protected for flat mailing.

9. Authors are responsible for obtaining and sending to us letters of permission to reprint copyrighted material, including illustrations.

10. Send us original and one copy of manuscript. Retain a third copy. Address manuscript and correspondence to:

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Acknowledgment of all manuscripts will be made as promptly as possible.

VETERANS ADMINISTRATION

1930